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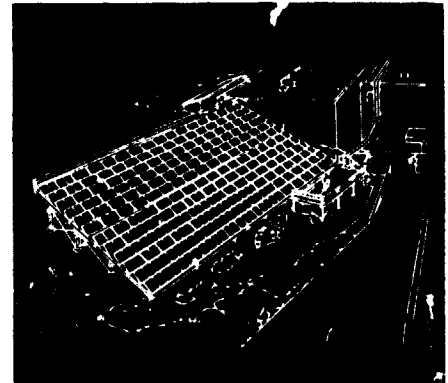
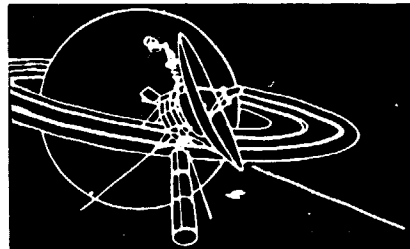
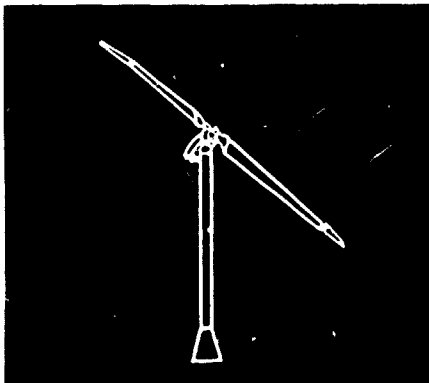
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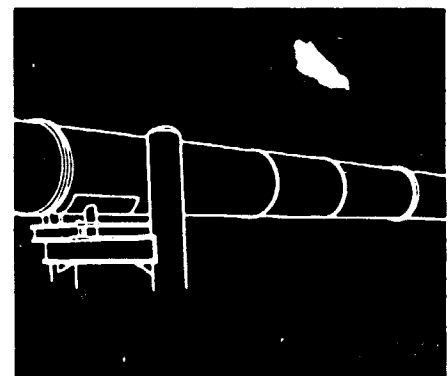
QUARTERLY REPORT NO. 1
**INTEGRATED RESIDENTIAL PHOTOVOLTAIC
ARRAY DEVELOPMENT**



PREPARED UNDER JPL CONTRACT 955894
REPORT DATE: FEBRUARY 17, 1981



ADVANCED
ENERGY
PROGRAMS
DEPARTMENT



ENERGY SYSTEMS AND TECHNOLOGY DIVISION

GENERAL  ELECTRIC

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PREPARED UNDER JPL CONTRACT 955894

REPORT DATE; FEBRUARY 17, 1981

BY: N.F. SHEPARD, JR.

The JPL Low-Cost Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE.

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ABSTRACT

This first quarterly report produced under a contract to design, develop and demonstrate an optimum integrated residential photovoltaic array/module describes nineteen existing or proposed systems intended for residential applications. Each of these systems is rated against a comprehensive set of evaluation criteria in an effort to formulate three module design concepts for further study and analysis. This evaluation led to a number of observations which are enumerated and should be considered in future module and array designs.

Three module concepts are presented as baseline design approaches to be further analyzed and optimized. These options include: (1) a rectangular, direct-mounted, shingle-type module, (2) an integrally-mounted module with non-conductive exposed elements, and (3) an aluminum-framed, stand-off module. Preliminary design drawings are presented for each of these module configurations.

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SECTION 1

SUMMARY

SECTION 1

SUMMARY

The first stage of a design selection process to define an optimum integrated residential photovoltaic module/array is discussed in this report. Existing or proposed residential array designs were reviewed and evaluated using a set of criteria which was formulated to enable the selection of three baseline module/array concepts as candidates for a more detailed assessment of the relative merits when used in an integrated residential application. The emphasis of this study is on a systems level approach to the development of detailed module/array design requirements and in the formulation of an optimum design solution which best meets these requirements.

As the first step of the process, a comprehensive list of 39 evaluation criteria was developed to permit the qualitative assessment of 19 existing or proposed residential array designs. Each of these criteria is described along with the module/array attributes which would contribute to a rating with respect to this criterion. The current technology base for residential photovoltaic systems is represented by these 19 existing or proposed design. In the majority of these cases a detailed array and systems design, which uses an available module, has been performed, and in many instances a prototype of the design has been constructed. The Northeast Residential Experiment Station (NE RES), shown in Figure 1-1, is the site of five such prototype systems - three of which have been installed as of the date of this report.

The lessons learned from this existing array designs have been incorporated into baseline module concepts which represent three different implementation approaches including a rectangular overlapping shingle, an integrally mounted module with a plastic tray substrate, and a stand-off mounted module with an aluminum frame.

System level considerations which influence the selection of module size are discussed and the rationale leading to the selection of a basic 2 by 4 foot configuration is presented.

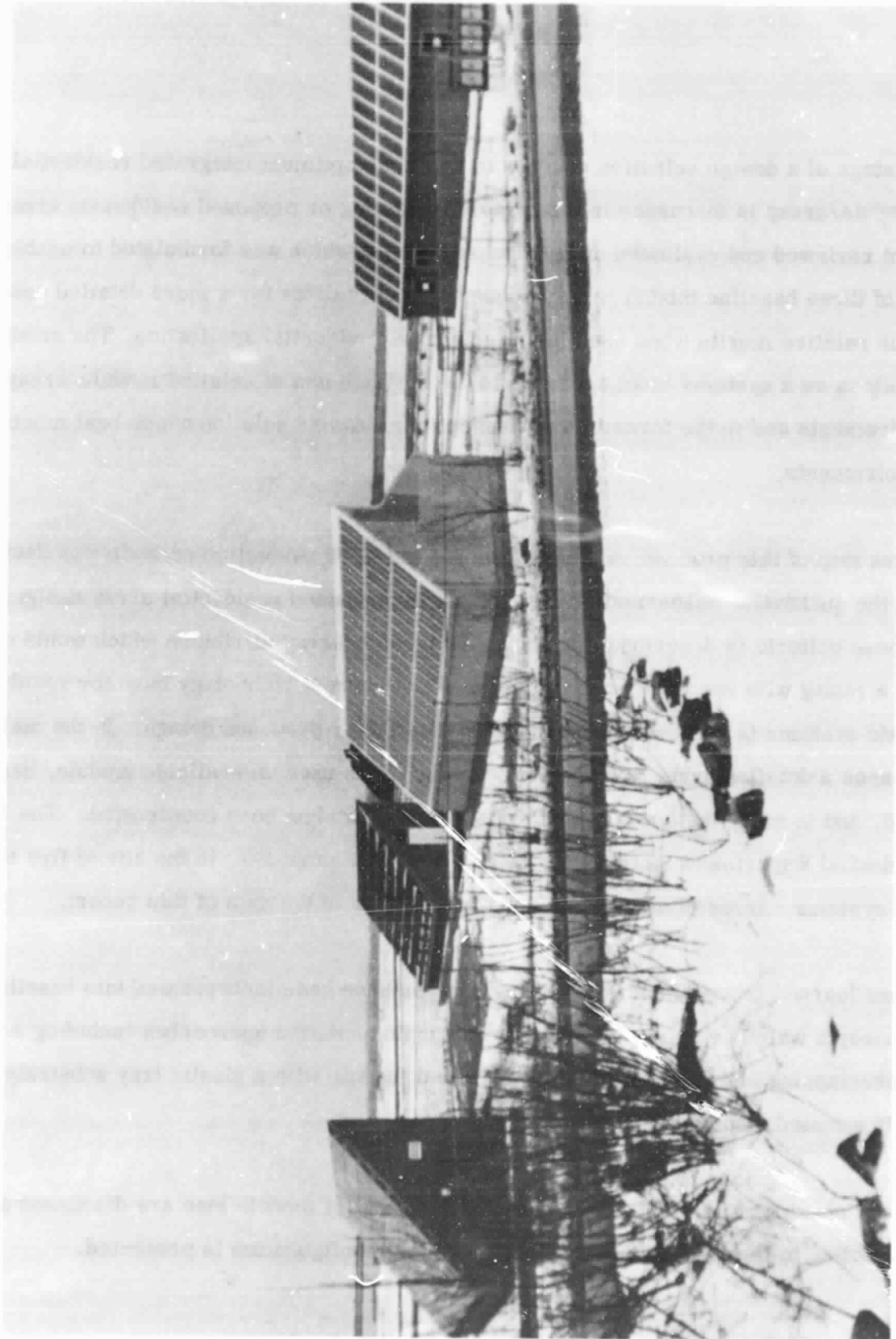


Figure 1-1. Existing Residential Array Designs are Exemplified by the NE RES Installations

SECTION 2

INTRODUCTION

SECTION 2

INTRODUCTION

The objective of this contract is to develop an optimized integrated residential photovoltaic array concept and to prepare detailed design definition which includes sufficient information to permit fabrication, assembly, and installation by a competent third-party. A prototypical simulated roof section of the optimized design concept will be constructed to demonstrate the fabrication and installation features of the photovoltaic array. The program activity is organized into three major tasks as listed below.

Task 1 - Development of Conceptual Alternatives

Task 2 - Optimize Design of One Concept

Task 3 - Fabricate Prototype Array/Roof Section

The Task 1 effort addresses the development and justification for the selection of three (3) generic integrated photovoltaic array design concepts for residential applications. This effort began with the formulation of a comprehensive set of criteria against which residential photovoltaic design concepts can be evaluated and rated. These concepts, which represent both existing or proposed array designs, were investigated and described. The evaluation of these designs against the established criteria leads to the synthesis of three different generic concepts which will be modified and optimized by the evaluation of installation and mass production costs.

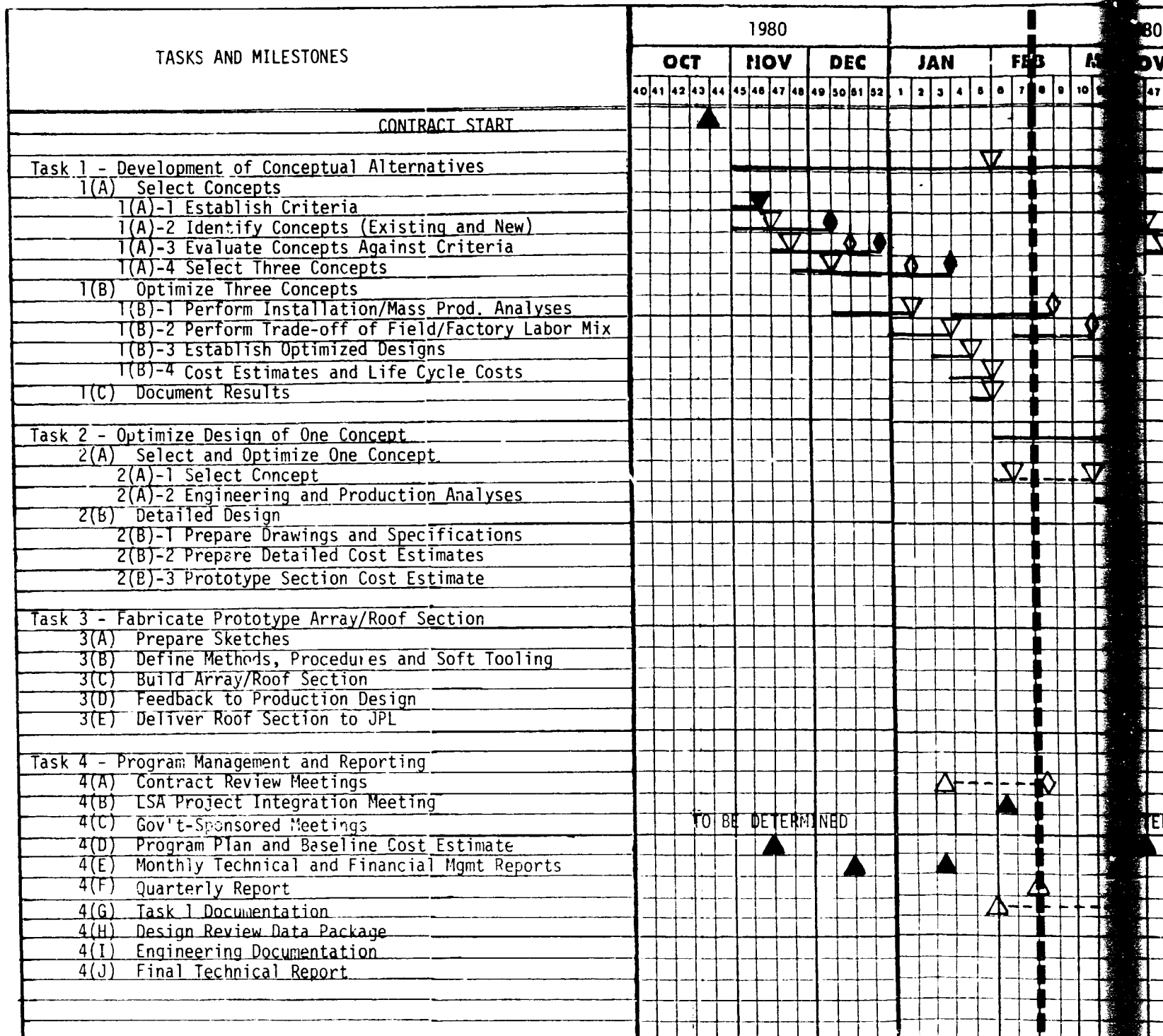
Based on the results of the Task 1 activity described above, one integrated residential array design concept will be selected for further analysis and evaluation under Task 2. Detailed production design development and engineering trade-off studies will be performed to further optimize the design for minimum life-cycle cost for the installed array. A set of drawings and specifications will be prepared to describe the module and array design. Based on this detailed information, refined life-cycle cost estimates will be generated for annual production levels of 10000, 50000 and 500000 m². In addition, a full-scale prototype array roof section will be defined and a cost estimate prepared for its fabrication.

The Task 3 activity will include the fabrication of a full-scale representative prototype section of the selected residential photovoltaic array complete with electrical and mechanical interconnectors and array/roof interface hardware. This prototype section, which need not be electrically operational, will serve as a model in identifying additional manufacturing, installation, maintenance and other interface concerns.

The master program schedule for this activity, which is reproduced as Figure 2-1, indicates the status of the effort as of this reporting date. All effort has been completed under Task 1(A) which includes the establishment of the evaluation criteria, the identification of existing concepts, and the evaluation of selection of three concepts. This report describes the results of this activity.

It is anticipated that the module/array concept developed under this contract will be designed and constructed to meet the requirements for Block V residential applications as reflected in JPL Documents 5101-162 and 5101-164. Preliminary releases of these documents, as reviewed at the Flat Plate Module/Array Safety Design Workshop on February 3, 1981, contains several requirements which differ from those imposed on the Block IV procurement. These differences, which are felt to have a significant effect on module design, are enumerated below with a description of the current requirements.

1. Module output power referenced to Nominal Operating Conditions (NOC). NOC is defined as an irradiance level of 80 mW/cm^2 , Air Mass (AM) 1.50 spectrum, and cell temperature equal to the Nominal Operating Cell Temperature (NOCT) which is also referenced to a 80 mW/cm^2 insolation.
2. Inclusion of module peak power rating. The peak power rating of the module must be stated at 100 mW/cm^2 irradiance, AM 1.5 spectrum, and 25°C cell temperature.
3. Ability to be series-connected to worst-case open-circuit voltage of 300 Vdc. All module circuitry, including output terminations, shall be insulated from external surfaces. The voltage isolation design shall provide capability of withstanding a worst-case, open-circuit system voltage of 300 Vdc, when modules are connected in



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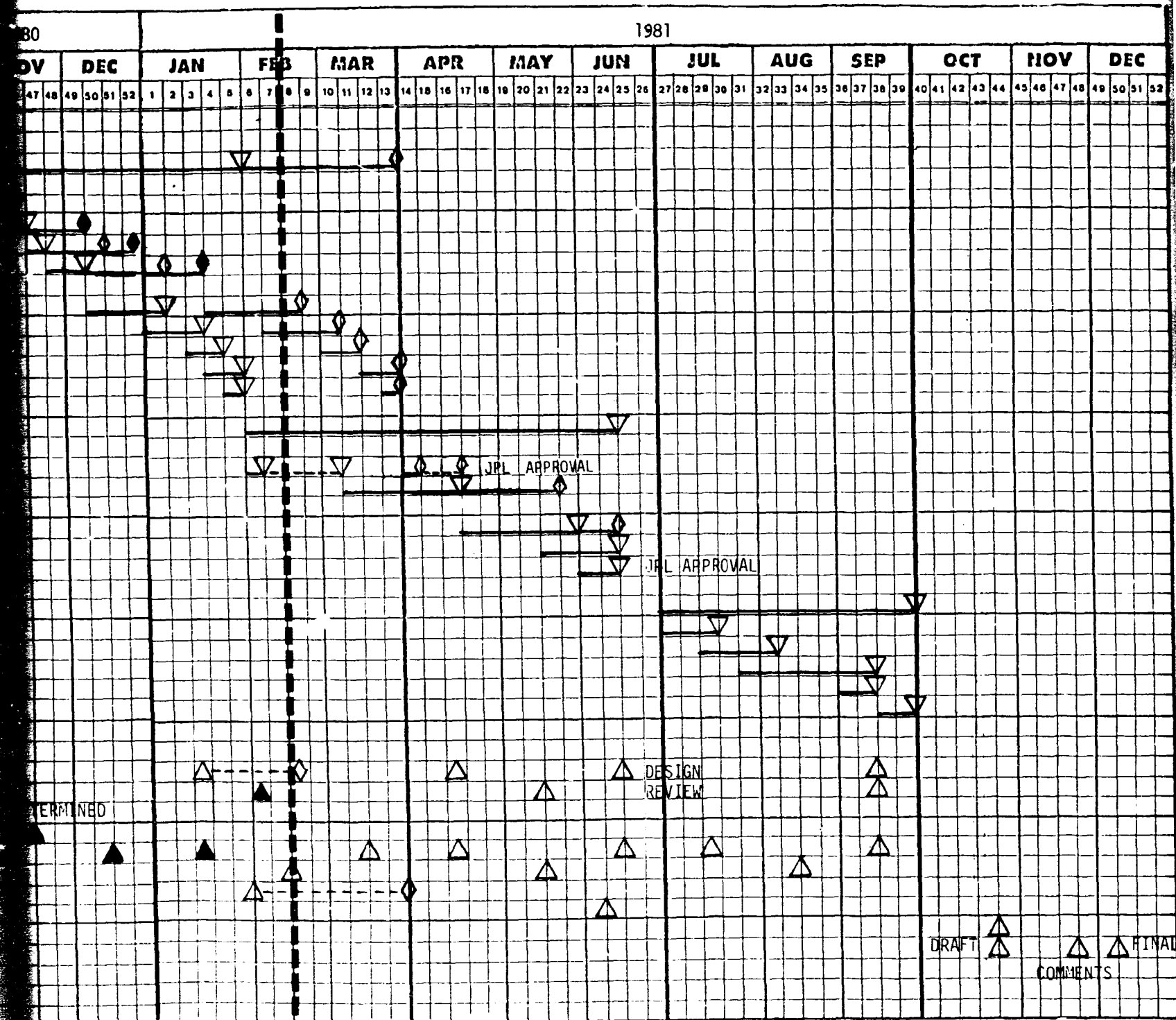


Figure 2-1. Master Program Schedule

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series, at 100 mW/cm² irradiance and 0°C cell temperature. This capability shall be demonstrated by ability to withstand the 1500 Vdc high-voltage (hi-pot) test.

4. Cell string reliability and redundancy. Circuit redundancy features shall be incorporated so that the loss in module output power at NOC shall be less than 10 percent under any of the following failure conditions:
 - (a) A single solar cell is separated into two parts by a single straight-line crack with any orientation or position within the cell.
 - (b) A single interconnect attachment point to a single solar cell is open-circuited.
 - (c) A single solar cell is short-circuited.
5. Module hot-spot endurance. The module shall be capable of withstanding, for its design life, the hot-spot heating caused when the module is short-circuited at 100 mW/cm² solar irradiance, 20°C air temperature, and any of the following conditions occur:
 - (a) Shadowing of any portion of any single solar cell.
 - (b) Separation of any single solar cell into two parts by a single straight-line crack with any orientation or position within the cell.
 - (c) Open-circuiting of any single interconnect attachment point to any single solar cell.
 - (d) Short-circuiting of any single solar cell.

This capability shall be demonstrated by the ability to withstand a specified Hot-Spot Endurance Test.

6. Maximum module open-circuit voltage. The module open-circuit voltage shall not exceed 30 Vdc under worst-case conditions of 100 mW/cm² and 0°C cell temperature.
7. Fire resistance. A photovoltaic module or panel in combination with a prescribed roof, and a photovoltaic module intended for mounting as the roof covering itself, shall meet the requirements of Class A, B, or C as defined in UL-790.

8. Humidity-freeze cycle test. A 10-day humidity-freeze cycle test at 85 percent relative humidity between the temperature extremes of 85 and -40°C is specified.
9. Thermal cycle test. The duration of the thermal cycle test has been increased to 200 cycles.

SECTION 3
TECHNICAL DISCUSSION

SECTION 3

TECHNICAL DISCUSSION

3.1 DEFINITION OF EVALUATION CRITERIA

The criteria to be used in the evaluation of the various existing or proposed residential array installations were formulated as the first step of the evaluation process which ultimately led to the selection of three array/module concepts described later in this report. These criteria, as identified in Table 3-1, encompass the gamut of technical, economic and institutional concerns associated with a residential photovoltaic array installation. The 39 criteria have been organized and grouped into seven broader categories as shown in the table. It was felt that such a grouping would provide a visualization of the relative strengths and weaknesses of the various concepts with respect to a given area of concern such as "Compatibility with Residential Construction," which is considered as being represented by five criterion.

An explanation and amplification of each criterion is given below:

A. Pre-installation factors

1. Module factory cost

Module factory cost is evaluated as the cost per rated watt at NOC for a baseline production rate.

2. Ease of storage, shipping and handling

This criterion encompasses those module characteristics that impact on storage, shipping, and handling functions, including:

- the number of modules which can be stacked together as a unit for shipment, storage and handling
- the need and extent of packaging
- the need and extent for special precautions such as protection from the weather during storage
- the need for special equipment such as a fork lift truck

Table 3-1. Criteria for Residential Array Concepts Evaluation

<p>A. Pre-Installation Factors</p> <ul style="list-style-type: none"> • Module Factory Cost • Ease of Storage, Shipping and Handling • Product Maturity • Shipping Weight per Unit Area • Shipping Volume per Unit Area • Shipping and Handling Durability <p>B. Compatibility with Residential Construction</p> <ul style="list-style-type: none"> • Compatible with Standard Construction Practice • Standard Tools and Equipment • Minimum Risk to Normal Building Function • Structural Compatibility with Building • Construction Trade Compatibility <p>C. Installation</p> <ul style="list-style-type: none"> • Need for additional or special weatherproofing • Minimum Added Structure • Electrical Connections per Unit Area • Mechanical Attachments per Unit Area • Ease of Handling • Installation Handling and Durability • Field Cabling Required • Ease of Grounding 	<p>D. Maintenance and Warranty</p> <ul style="list-style-type: none"> • Maintenance Frequency • Ease of Module Replacement • Overlap of Warranty Responsibility • Interference with Normal Building Maintenance • Susceptible to Vandalism • Safety • Product Life <p>E. Operation</p> <ul style="list-style-type: none"> • Array Efficiency at NOC • Operating DC Voltage Compatible with Existing Inverter Requirements • Reliability • Weatherability • Safety
	<p>F. Potential for Code Compliance</p> <ul style="list-style-type: none"> • Potential to Meet UL 790 Class B (Fire) • Potential to Meet National Electric Code Requirements • Capability with Existing Building Codes <p>G. Acceptance</p> <ul style="list-style-type: none"> • Aesthetics • Insurability • Application Flexibility • Builder/Architect Acceptance • Homewoner/Community Acceptance

3. Product maturity

Product maturity relates to the status of product development and potential or capability for manufacture at the baseline production rate.

4. Shipping weight and volume per unit area

The areal shipping weight and volume describe the bulk packaging characteristics of the module, and when coupled with stackability, are the major factors influencing the cost for shipping and storage.

5. Shipping and handling durability

This criterion addresses the vulnerability of the module to damage or deterioration during pre-installation phases of shipping and handling, and reflects both the durability enhancement provided by any required packaging, and normal shipping and handling practice. Items considered in this category include:

- overall potential for damage to module
- potential for interconnect damage
- potential for cell breakage due to flexure of the substrate or superstrate

B. Compatibility with residential construction

1. Compatible with standard construction practice

The installation of some modules may require the development and implementation of methods of roof construction that are not currently considered as standard practice. Factors to be considered here include:

- module configuration impact on spacing of roof structural elements (e.g., rafters, purlins)
- array conflict with other roof features (e.g., vent pipe, chimney)
- need for tolerances tighter than standard carpentry practice
- need for roof modification (e.g., removal of plywood, reinforcement of standard rafters, addition of purlins, rafter crossbracing)
- need for non-standard flashing and sealants

2. Standard tools and equipment

The installation of some modules may require special tools or may require special material handling equipment (e.g., cranes, ladders, hoist, etc.)

3. Minimum risk to normal building function

Some modules may exhibit characteristics or involve installation features that adversely impact on the normal functions of the building, including:

- module increases risk for rain leakage
- module encourages nesting of squirrels, birds, vermin, or accumulation of debris

4. Module structural compatibility with supporting structure

Depending on the type of installation, some modules may be required to withstand structural loads imposed by wind, snow, and their own dead weight. In meeting this requirement, it may be necessary to provide additional structural support to the module. Modules must not reduce overall structural integrity of buildings.

5. Construction trades compatibility

Building construction particularly within a trade union context, is performed in accordance with a rigidly defined demarcation between job function. For example, electrical work is performed exclusively by electricians while roofing is performed only by members of roofers union. PV modules by their very nature appear to fall within the domain of electrician; however, their installation and maintenance might also involve other trades such as carpenters and roofers. This potential for multi-involvement of trades is not necessarily detrimental unless ambiguity of responsibility, or a conflict between construction trades, or a redundancy of manpower results.

C. Installation

1. Need for additional or special weatherproofing

Additional or special weatherproofing to protect either the module or the building beneath it may be required for permanent protection; or for temporary protection during periods when installation is interrupted by weather or end-of-day.

2. Minimum added structure

Some module installations may require supporting structural elements which would not otherwise be required for the residence if it did not have a photovoltaic array. This criterion also applies to required increases in the size or quantity of standard residential structural elements which are dictated by the type of photovoltaic installation and/or the interaction of the array and the building. For example, roof mounted arrays (integral, direct, stand-off, rack) may require additional roof structure to meet any increase in loads caused by the presence of the modules, or to accommodate a separate module support structure.

3. Electrical connections per unit area

The cost and complexity of installation tends to increase with the number of electrical connections between modules, and is greater for the traditional J-box wiring connections than for modular quick-connect terminations.

4. Mechanical connections per unit area

The cost and complexity of installation tends to increase with the number and type of mechanical connections between adjacent modules, and between module and support structure. Simple accessible connections (e.g., nailing or stapling) are preferred over those which add to installation time.

5. Ease of handling (by one or two persons)

Module size and weight contribute to the ease of handling during installation. Most residential tasks are accomplished by one or two persons, each with a hand-to-hand comfortable grip span of 36 to 40 inches and an individual lifting capacity of 50 to 60 lbs. Modules with size and weight which exceed the physical

limitation of two persons will generally require the use of special mechanical lifting or positioning equipment.

6. Installation handling durability

During installation, modules may be exposed to unevenly distributed loads, such as bending or flexure, arising from workmen standing on modules or from other typical manual handling practices. Modules designed to withstand or accommodate these handling loads will facilitate the installation without jeopardizing operational performance.

7. Field cabling required

Field installed cabling will be required on any photovoltaic array, but the extent of such wiring is a function of the specific module design and array layout. The placement of the field wiring within a sheltered environment can be expected to reduce the labor cost when compared to an equivalent installation which requires the electrician to work outdoors.

8. Ease of grounding

The JPL specifications defining the requirements for flat-panel terrestrial photovoltaic modules have historically included the requirement for grounding of exposed external conductive surfaces. A terminal or stud must be provided to serve as a common grounding point for exposed conductive surface. A grounding connection is not required for modules without exposed conductive surfaces. The need for grounding, which is not present on modules of the latter type, has an obvious negative impact on the field wiring cost and on the overall safety and reliability of the array.

D. Maintenance and Warranty

1. Maintenance frequency

Some modules, by the very nature of their design, increase the need for maintenance. Factors to be considered include:

- Dirt or debris accumulation, which is caused by module surface features, and which must be removed to prevent a performance reduction. For

stand-off modules debris may also accumulate under the modules, thereby insulating the back face and resulting in higher cell temperatures and lower output.

- Susceptibility of exposed parts to rust and corrosion.
- Wooden components requiring periodic painting.
- Gasketed joints requiring replacement for leak-free performance over the array design lifetime.

2. Ease of module replacement

This criterion reflects the difficulty, cost or time involved in the identification of failed modules and in the removal and replacement of these failed modules. Specific items which may be considered include:

- Accessibility of module. Can modules be walked on or is special equipment necessary to reach module?
- Can module removal and replacement be performed in the daytime?
- Can the module be removed from the array without disturbing adjacent modules?
- Is there a simple procedure for the location of failed modules?

3. Overlap of warranty responsibility

A module or array warranty, when offered, may be invalidated or compromised by the need to remove stand-off mounted modules when repair of the underlying roof is necessary. Similarly the warranty on a conventional asphalt shingle roof may be of little value if the surface is penetrated by the brackets required to support a stand-off array installation.

4. Interference with normal building maintenance

Normal building maintenance, such as roof repair, gutter cleaning, and painting around eaves, may become more difficult due to the presence of roof mounted arrays. Assessment of this category should reflect the degree of difficulty imposed on normal building maintenance.

5. Susceptibility to vandalism

The threat of vandalism to PV arrays will probably be proportional to the accessibility of the array, with the greatest threat to ground mounted arrays. Assessment of this category should account for both accessibility and vulnerability of modules to thrown objects. Annealed glass covered modules are more susceptible to damage from thrown objects than are tempered glass covered modules.

6. Safety

Safety refers to those module features which tend to increase the risk to personal safety or property during installation and maintenance, and include:

- weight and size of modules to be lifted to point of installation at the same time
- potential for accidental shock
- restrictive installation, procedure requiring awkward or unstable workmen positioning

7. Product life

Some modules may incorporate materials or design features that tend to limit product life. For example, the use of a polymeric outer cover should result in a useful product life which is less than a comparable glass-covered module.

E. Operation

1. Array efficiency at NOC

The array efficiency at NOC is defined by the following ratio:

$$\frac{\text{Array Maximum Power Output}}{(\text{Gross Array Area, m}^2) (800)}$$

The array maximum power output (watts) is measured or referenced to Normal Operating Conditions (NOC) which reflect an ambient temperature of 20°C, a wind speed of 1 m/s and an insolation of 800 w/m².

2. Operating DC voltage compatible with existing inverter requirements

Available inverters have an input voltage range which must be maintained for satisfactory operation. The size and output of the module, and the type and location of the electrical connectors should not constrain the array layout so that the resultant circuit does not meet this voltage requirement for typical residential roof sizes and aspect ratios.

3. Reliability

Per JPL module design and test specifications, module reliability is related to module circuit redundancy features, which may include, but are not limited to the following:

- Redundant interconnections between solar cells, including redundant cell attachment points
- Series/parallel interconnection of cells within the module
- Integral bypass diodes within each module

The decision to incorporate redundancy features shall be based on the expected percent improvement in lifetime/yield and replacement cost as contrasted with the percent increase in module cost/watt. Series/parallel circuit arrangements, when used, shall be designed so that "hot-spot" cell heating does not lead to further module degradation under worst-case-single-cell-failure conditions defined as follows:

- The module output is short circuited
- A single representative solar cell is open circuited to represent a single cell failure
- The incident irradiance is 100 mW/cm^2 , AM1.5
- The thermal boundary conditions are adjusted so that the equilibrium solar cell temperature outside of the hot-spot region is equal to $\text{NOCT} + 20^\circ\text{C}$

4. Weatherability

Weatherability refers to the module's ability to withstand the deleterious effects of the environment while maintaining the as-installed appearance and performance characteristics. For instance, plastic cover materials generally exhibit a photo-degradation of optical transmission which is not present with a glass cover. Other features that are related to weatherability include the ability of the module surface to shed dust and dirt, as well as the potential for mildew, corrosion, rot, decay.

5. Safety

Under this category safety refers to the degree of hazard imposed by the operation of the array, and may include:

- increased fire hazard to roof
- the generation of high voltage, particularly if this occurs near the eave of the roof

F. Potential for code compliance

The three criterion under this category address the potential for module code compliance which can be estimated on the basis of existing requirements for residential construction and electrical elements which are functionally similar to the module. The more widely recognized building codes will be used in this evaluation and include:

1. UL 790 (Fire)
2. National Electric Code (NEC)
3. Regional building codes
 - Building Officials and Code Administrators (BOCA) Basic Building Code
 - Southern Building Code Congress (SBCC) Standard Building Code
 - International Conference of Building Officials (ICBO) Uniform Building Code

G. Acceptance

1. Aesthetics

The appearance of a house is very important to the buyer. The house market tends to be conservative, reflecting the tastes of the average buyer and his concern for resale. The PV module/array should conform to this conservative aesthetic, blending in with the surroundings and not drawing attention. Module/array characteristics that impact on aesthetics include:

- size
- shape
- color
- texture
- pattern

2. Insurability

While insurance companies do not currently have provisions covering the application of photovoltaic arrays to residential dwellings, the question of insurability is of concern since it might ultimately have a significant impact on the acceptance of the technology for privately-owned residential installations. At present it can be assumed that the array would be treated as part of the dwelling, and its value incorporated in the total replacement value upon which the insurance premium is based. The durability of the module will probably be the most important factor in the establishment of insurance rates, and includes resistance to damage from natural causes, accidents, and vandalism. It is likely that array installations which are divorced from the normal building functional elements will be looked upon with favor by the insurance underwriters.

3. Application flexibility

This criterion addresses the ability of a given module/array concept to be adapted to a variety of residential architectural styles. For example, a rack-mounted array can be integrated well with a flat-roof dwelling, but can not be easily

adapted to a sloping gable roof. On the other hand, a direct-mounted, overlapping shingle module is ideally suited for such a sloping roof and loses many of the advantages when considered for installation on a flat-roof building.

4. Builder/architect acceptance

Acceptance by the builder/architect community includes many factors which are enumerated elsewhere in this list but its inclusion within this category is intended to emphasize the importance of this aspect of the array design. Factors such as compatibility with standard construction practice, aesthetics, potential for code compliance, and construction trades compatibility contribute to the acceptance of a given concept by the builder/architect.

5. Homeowner/community acceptance

This criteria also encompasses many of the items previously discussed, but these are not necessarily the same concerns which could contribute to builder/architect acceptance. It is expected that the lay person, who is a potential owner of a photovoltaic-powered house, would consider factors such as cost, product maturity, maintenance frequency, reliability, insurability, and aesthetics before making the decision to purchase.

3.2 DESCRIPTION OF EXISTING OR PROPOSED RESIDENTIAL ARRAY DESIGNS

The nineteen photovoltaic systems listed in Table 3-2 represent existing or proposed residential array designs. In each case a detailed system design has been completed and architectural and engineering drawings have been developed to permit the construction of the photovoltaic installation. Several of the designs listed in this table have been or will be constructed as prototype installations at the Northeast Residential Experiment Station (NE RES) located in Concord, MA. In particular the systems designed by MIT-LL using stand-off mounted Solarex Block IV modules, Westinghouse using ARCO-Solar commercial modules in an integral mounting scheme, and Trisolar Corp. using integrally-mounted Block IV ASEC modules, have been installed as of the date of this report. These array implementation approaches represent a wide range of residential installation options which are worthy of study in an effort to optimize the design of a module for this application. As shown in Figure 3-1 the MIT-LL residential

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Application Description	System Contractor	Module Supplier	Module Development Status	Module Mounting Approach	Brief Module Description	Substrate/ Back Cover	Encapsulant
1) John Long Homes	John Long Homes	ARCO-Solar	BIV ⁽¹⁾	Direct	Batten/Metal Roofing Panel, Circular Cells	Tedlar/Steel	EVA
2) Florida Solar Energy Center	State of Florida	ARCO-Solar	Commercial	Stand-off	ASI16-2300, 35 series-connected 4" Dia cells	Tedlar/Al Foil	PVB
3) Hawaii Natural Energy Institute	State of Hawaii	ARCO-Solar	BIV	Direct	Batten/Metal Roofing Panel, Circular cells	Tedlar/Steel	EVA
4) Hawaii Natural Energy Institute	State of Hawaii	ARCO-Solar	Commercial	Stand-off	ASI16-2300, 35 series connected 4" Dia cells	Tedlar/Al Foil	PVB
5) NE RES and NE ISEE	MIT-LL	Solarex	BIV	Stand-off		Tedlar	EVA
6) NE and SW RES	GE	GE	BIV+ ⁽²⁾	Direct	Overlapping hexagon shingle, 19 series-connected 100 mm Dia cells	Pan-L Board	Silicone
7) NE and SW RES	Westinghouse	ARCO-Solar	Commercial	Integral	ASI16-2300, 35 series-connected 4" Dia cells	Tedlar/Al Foil	PVB
8) NE and SW RES	Solarex	Solarex	BIV+	Stand-off	Modified BIV module, 100mm square semi-crystalline cells, 72 cells connected, 36 series by 2 parallel, 6 by-pass diodes	Tedlar	EVA
9) NE RES	Trisolar	ASEC	New	Integral	253 Quasi-square cells, 64mm across flats, 23 series by 11 parallel	Tedlar	PVB
10) SW RES	Trisolar	ASEC	BIV+	Integral	190 Round cells, 76mm dia, 19 series by 10 parallel	Tedlar	PVB
11) SW RES	ARCO-Solar	ARCO-Solar	BIV+	Direct	ASI15-2200 Batten/Metal Roofing Panel, 60 circular cells 4" Dia, 3 parallel-connected circuits of 20 series cells each	Tedlar/Steel	EVA
12) SW RES	BDM	Motorola	BIV+	Stand-off	33 Quasi-square cells, 100mm across flats, 33 series by 1 parallel, 1 diode per 11 series cells	Aluminized Tedlar	PVB
13) SW RES	ARTU	ARCO-Solar	Commercial	Stand-off	ASI16-2300, 35 series-connected 4" Dia cells	Aluminized Tedlar	PVB
14) SW RES	TEA	Motorola	BIV	Rack	33 Quasi-square cells, 100mm across flats, 33 series by 1 parallel, 1 diode per 11 series cells	Aluminized Tedlar	PVB
15) First Preferred Design Study ⁽³⁾	N/A	GE	BIV	Direct	Overlapping hexagon shingle, 19 series-connected, 4 inch diameter cells	Pan-L Board	Silicone
16) Second Preferred Design Study ⁽³⁾	N/A	ARCO-Solar	BIV+	Direct	Batten/metal roofing panel, 100mm sq. cells, 16 series by 7 parallel connected cells	Tedlar/Steel	EVA
17) Third Preferred Design Study ⁽³⁾	N/A	Solarex	BIV	Stand-off	Intermediate BIV module, 95mm square semi-crystalline cells, 72 cells connected 36 series by 2 parallel, 36 by-pass diodes	Tedlar	EVA
18) Fourth Preferred Design Study ⁽³⁾	N/A	GE	New	Direct	Overlapping rectangular shingle, 95mm square cells, 96 cells for full-size module, 48 cells for half-size module	Pan-L Board	EVA
19) Fifth Preferred Design Study ⁽³⁾	N/A	GE	New	Integral			

(1) Module developed under the Block IV procurement

(2) Modification of a Block IV module design

(3) Represent detailed photovoltaic system designs performed under Sandia Contract No. 13-8779

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Table 3-2. Summary of Existing or Proposed Residential Array Systems

	Substrate/ Back Cover	Encapsulant	Superstrate/ Front Cover	Exposed Area Per Module (m ²)	Number of Modules	Total Array Roof Area (m ²)	Array Electrical Circuit Configuration
11s	Tedlar/Steel	EVA	Tedlar		125		Five branch circuits each consisting of 75 series-connected modules.
cells	Tedlar/Al Foil	PVB	Glass	0.368	168		
11s	Tedlar/Steel	EVA	Tedlar				
cells	Tedlar/Al Foil	PVB	Glass	0.368	112		
	Tedlar	EVA	Glass	0.762			
con-	Pan-L Board	Silicone	Glass	0.1955	375	85.1	One branch circuit consisting of 25 series by 15 parallel modules. No by-pass diodes.
cells	Tedlar/Al foil	PVB	Glass	0.368	156	75.6	One branch circuit consisting of 13 series by 12 parallel modules. One by-pass diode per 1 series by 12 parallel group.
	Tedlar	EVA	Glass	0.762	80	71.5	Ten branch circuits each consisting of 8 series-connected modules.
odes							
ts.	Tedlar	PVB	Glass	Proprietary	36	Proprietary	Two branch circuits each consisting of 18 series-connected modules, two parallel diodes per module
	Tedlar	PVB	Glass	1.285	44	58.14	Two branch circuits each consisting of 22 series-connected modules
	Tedlar/Steel	EVA	Tedlar		130	78	Five branch circuits each consisting of 26 series-connected modules, with one by-pass diode per module.
each	Aluminized Tedlar	PVB	Glass	0.426	117	55.34	Nine branch circuits each consisting of 13 series-connected modules.
ts, 11							
cells	Aluminized Tedlar	PVB	Glass	0.368	144		Twelve branch circuits each consisting of 12 series-connected modules, with one by-pass diode per module.
ts.	Aluminized Tedlar	PVB	Glass	0.426	112	49.32	Eight branch circuits each consisting of 14 series-connected modules, center tapped
con-	Pan-L Board	Silicone	Glass	0.1955	475	92.9	One branch circuit consisting of 25 series x 19 parallel modules. No by-pass diodes
cells,	Tedlar/Steel	EVA	Tedlar	0.657	112	80.9	Four branch circuits each consisting of 28 series-connected modules. One by-pass diode per module
ts							
ni-	Tedlar	EVA	Glass	0.762	100		Ten branch circuits each consisting of ten series-connected modules. 36 by-pass diodes per module
36							
es							
quar-	Pan-L Board	EVA	Glass	0.916(full) 0.458(half)	52(full) 8(half)	55.1	One branch circuit consisting of 8 series x 7 parallel full-size modules - four by-pass diodes per module
43							

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array design for the NE RES is a unique stand-off mounting arrangement using Solarex Block IV modules. The installation of these modules is accomplished by rolling each column of modules up a track structure, as shown in Figure 3-2, using the specially-designed hand-crank mechanism pictured in Figure 3-3. As is typical of other stand-off mounted installations, this design approach provides a 3 to 4 inch air space between the rear side of the modules and the conventional asphalt shingle roofing surface as shown in Figure 3-4. The photograph reveals other components which are typical of installations of this type, viz., the grounding strap used to electrical bond exposed metallic elements, the watertight junction box, and the field-installed interconnecting wiring harnesses.

The Westinghouse-designed, integrally-mounted array using ARCO-Solar type ASI 16-2300 commercial modules is shown in Figure 3-5. This array consists of 20 perassembled panels which are each mounted as a unit within the rafters as pictured in the figure. Each of these panels is an assembly of eight ARCO-Solar ASI 16-2300 modules within an aluminum extrusion frame structure. Figure 3-6 shows these panels as stacked at the job site. The size and weight of these panels would require three or four installers to remove a panel from the stack and position it between the rafter.

An internal view of this installation, shown in Figure 3-7, reveals type NM wire being used to interconnect between the junction boxes attached to the rear of each ARCO-Solar module. Service loops have been provided in each of these connecting wire segments. Building detail drawings indicate that R-28 isocyanate insulation will be installed between the 2 x 12 roof joists and T-111 siding installed as a finishing on the interior roof surface. This provides a ventilation space directly under the panels but completely blocks access to the panels from the interior.

The TriSolar Corp. NE RES installation shown in Figure 3-8 represents another integrally-mounted array concept which employs 36 large area aluminum-framed ASEC modules. Figure 3-9, which pictures the installation in progress, shows the wider rafter spacing and the use of purlins for lateral support between rafters.

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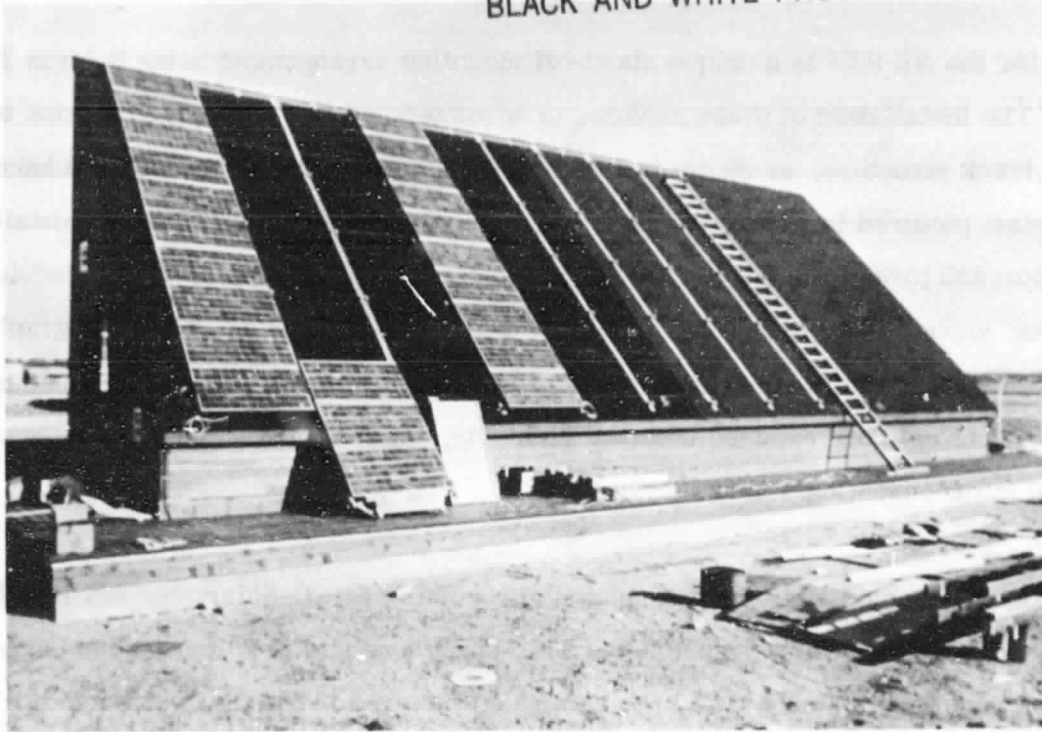


Figure 3-1. MIT-LL/Solarex Residential Array for the NE RES

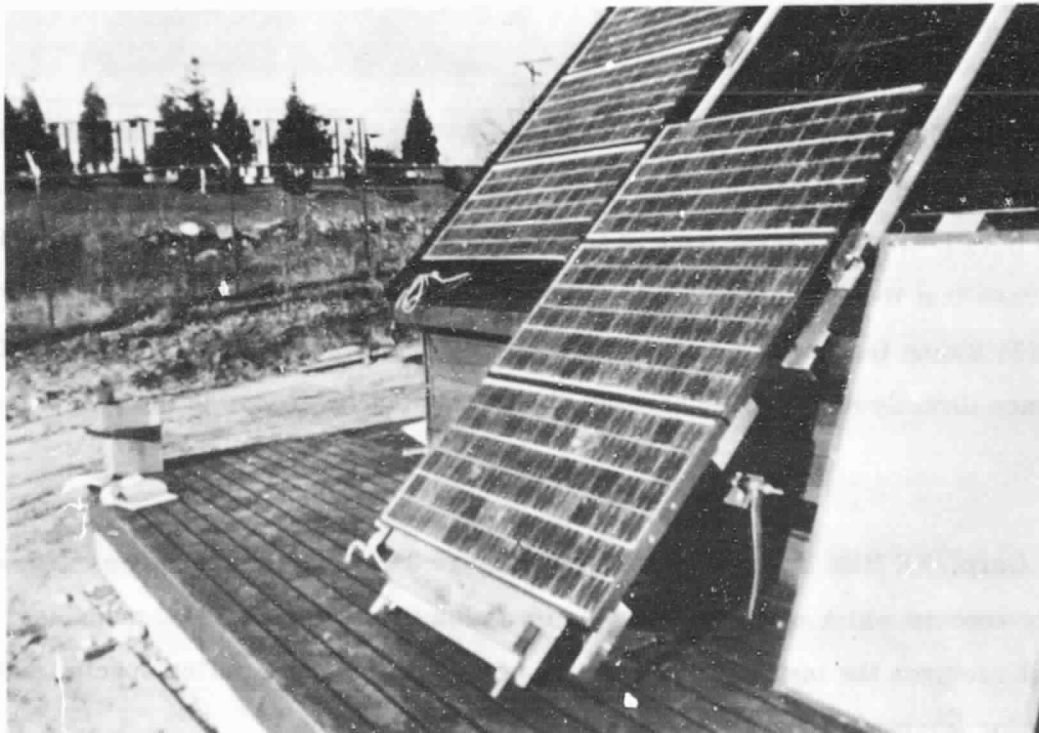


Figure 3-2. Details of Module Installation Method

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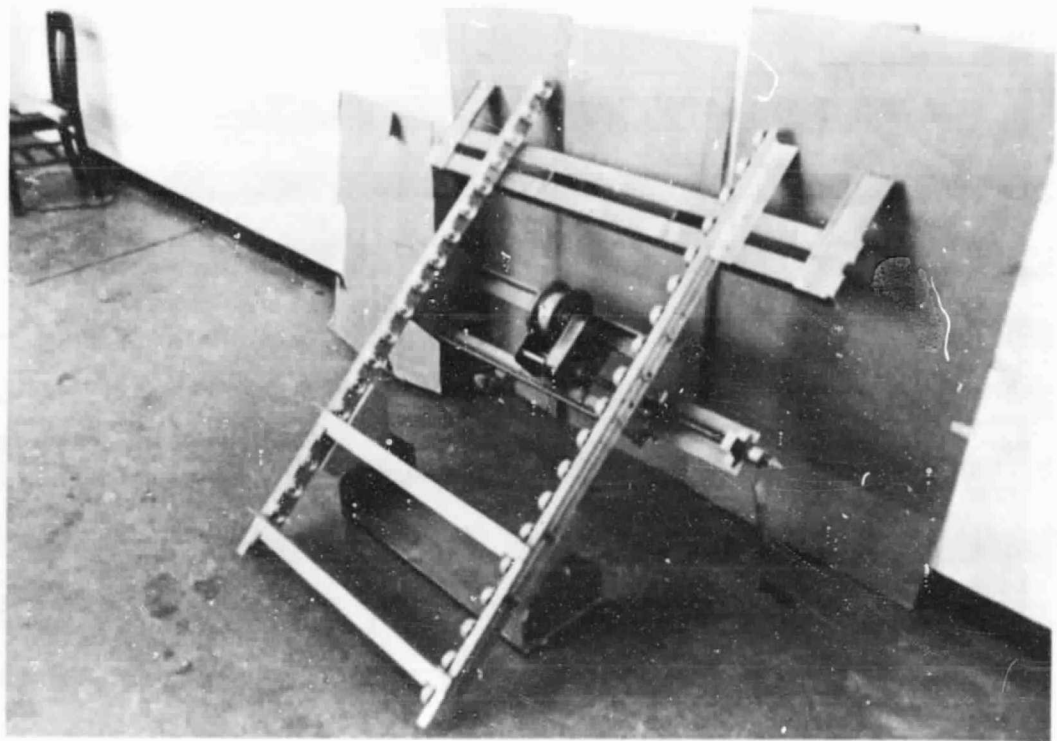


Figure 3-3. Hand-Crank Mechanism for the MIT-LL NE RES Installation

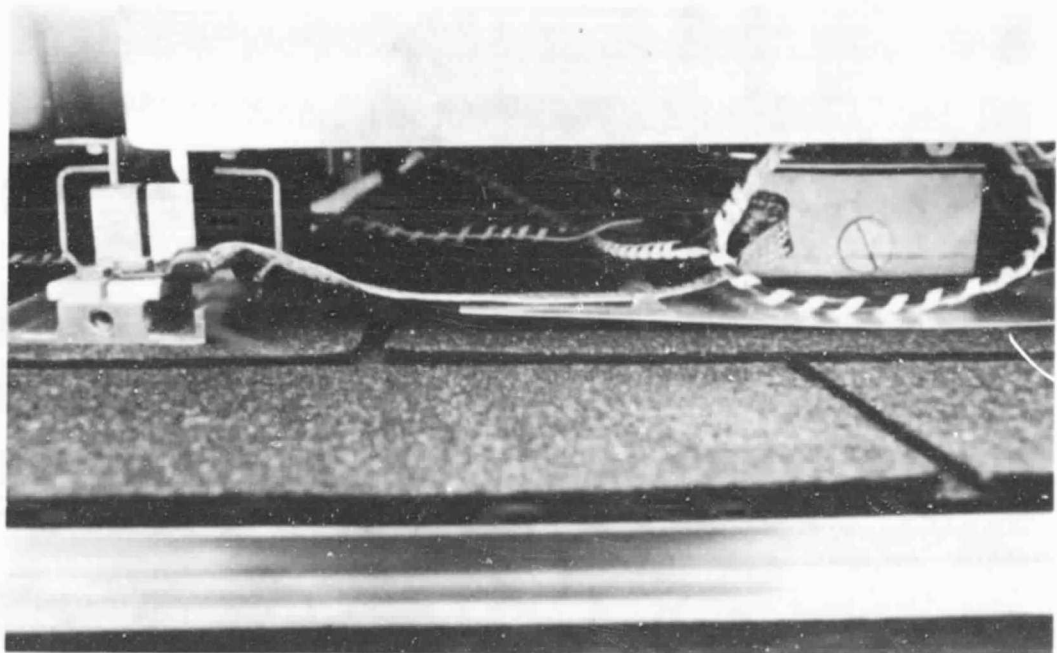


Figure 3-4. Detail of Track Structure and Wiring for the MIT-LL NE RES Installation



Figure 3-5. Westinghouse/ARCO-Solar Residential Array for the NE RES

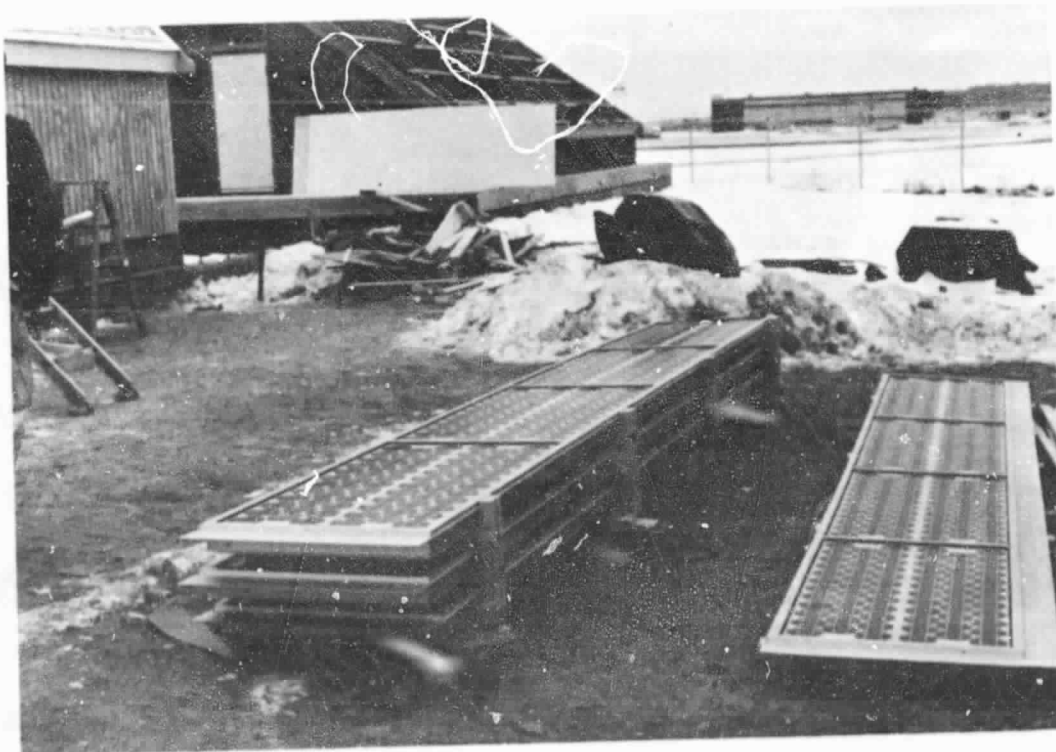


Figure 3-6. Pre-assembled Panels Stacked at Job Site

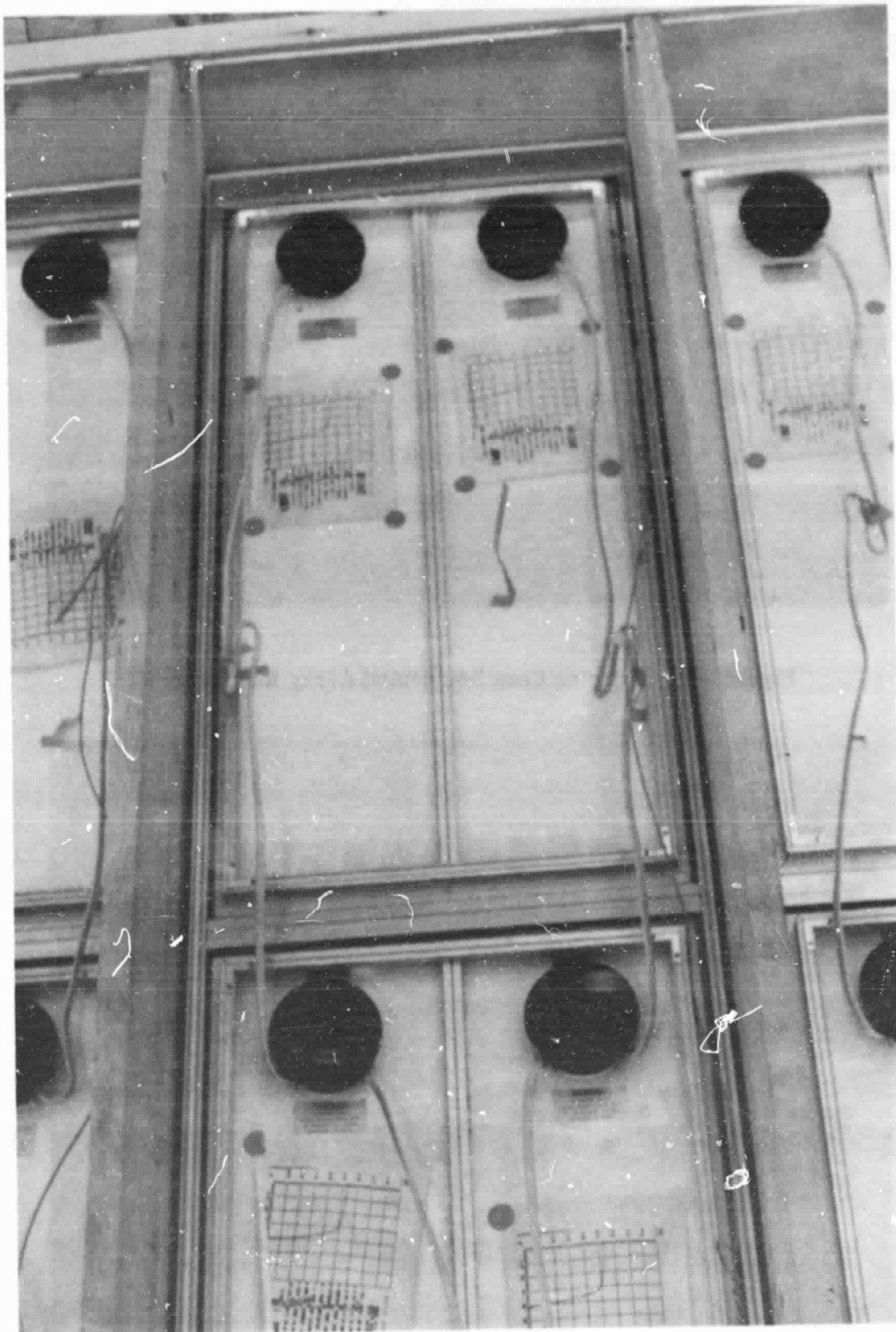


Figure 3-7. Module-to-Module Wiring on the Westinghouse Integral NE RES

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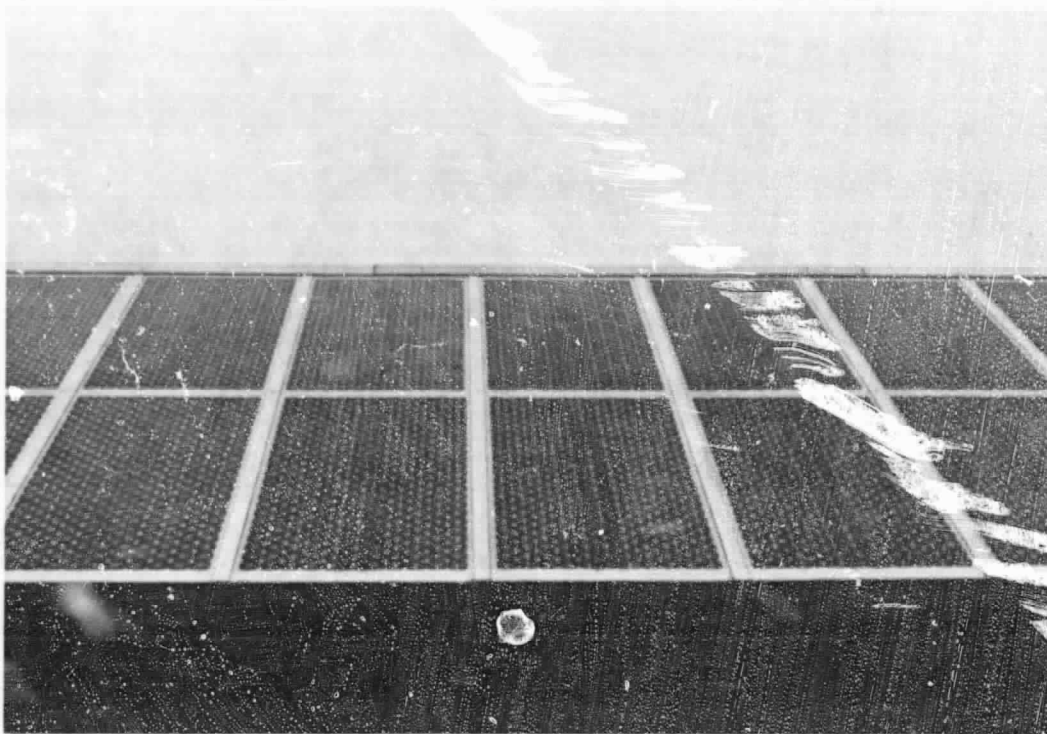


Figure 3-8. TriSolar Corp Residential Array for the NE RES

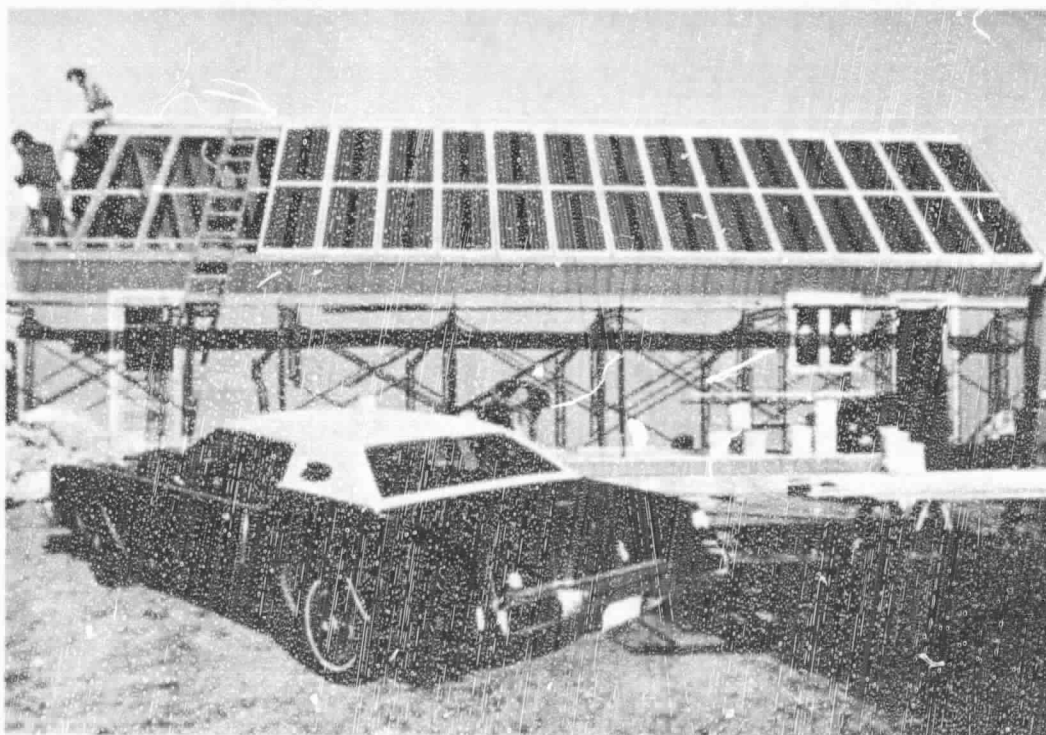







Figure 3-9. Installation of ASEC Modules in the TriSolar Corp NE RES

3.3 CONCEPT EVALUATION

The evaluation of each of the 19 existing or proposed concepts against the established criteria described in Section 3.1 was accomplished using a rating approach which scores each concept using a system of shaded circles to represent five possible rankings as shown below:

<u>Rating Symbol</u>	<u>Evaluation</u>
	Excellent
	Good
	Fair
	Poor
	Unsatisfactory (or very poor)

In this way it is possible to present a graphical display of the evaluation results as shown in Table 3-3. The various existing or proposed concepts have been listed across the top of the matrix. Similar concepts have been grouped together in a single column and identified by the concept numbers corresponding to the descriptions contained in Table 3-2. Numerical scores have been assigned for each of the seven broad evaluation categories and for the total of all criteria by adding the number of unshaded quadrants in each column of the matrix.

One nature this evaluation is subjective and reflects the opinion of the evaluator. This shortcoming must be appreciated even though attempts were made to incorporate the thoughts of several knowledgeable evaluators in the ranking process. It should also be emphasized that this method does not account for the fact that an unsatisfactory rating against a given criterion may be fatal to the application of a particular concept. Notwithstanding these evaluation concerns, it is felt that this method yields valid relative rankings in the broad categories established for the criteria and these results can be used to draw general conclusions regarding the application of a given concept to a residential photovoltaic installation.

A discussion and justification of every ranking in this matrix is impractical in a report of this type, but it might be useful to describe the issues which were considered and evaluated in the

scoring of each concept against several of the criteria. For example, the scoring of each concept with respect to "Construction Trade Compatibility" included the consideration of the number of building trades which could be simultaneously involved in a non-productive sense, due to work rule or union jurisdictional issues, in the installation of the photovoltaic array. Both stand-off and rank mounted concepts ranked high with respect to this criterion since in either case there is a clear functional and physical separation of the array from the roofing surface. The direct mounted approaches were ranked somewhat lower because there is the potential for roofers and electricians to be non-productively involved with the installation. The integrally-mounted concepts received the lowest rank for this criteria since the potential exists for carpenters, roofers and electricians to be involved by virtue of union work rule or jurisdictional reasons.





























The "Ease of Handling by One or Two Persons" criterion was evaluated based on the size and weight of the module or panel which is handled as a unit when lifting from ground to roof level. The pre-assembled Westinghouse/ARCO-Solar integral panels and the two systems which use the large ASEC modules were rated as unsatisfactory with respect to this criterion.

The evaluation of the "Array Efficiency at NOC" criterion included the consideration of the NOCT associated with each mounting approach as well as the overall array packing factor which is defined as the ratio of the cell area to the gross roof area. The highest rating for this criterion was assigned to the rectangular shingle module and to the large area ASEC module with the quasi-square high efficiency cells. The Westinghouse/ARCO integrally-mounted array received the lowest rating due to the poor overall array packing factor.

The results of this evaluation process, which are summarized at the bottom of the table as a total score for each concept, lead to several general conclusions or observations as discussed below:









































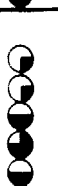





















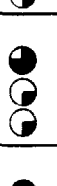


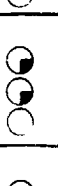
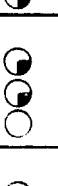





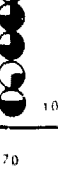








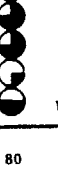


1. Direct-mounted concepts rank high. The direct-mounted overlapping shingle approaches ranked high in this evaluation. The ARCO batten module, which is also classified as a direct-mounted approach, was negatively impacted by several safety and durability related design features which could be corrected to yield an equally high ranking.

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CRITERIA FOR THE TASK 1 ARRAY CONCEPTS EVALUATION	ARCO-SOLAR BLK IV DIRECT (1, 3, 11)	ARCO-SOLAR COMMERCIAL INTEGRAL (7)	ARCO-SOLAR BLK IV + DIRECT (16)	ARCO-SOLAR COMMERCIAL STAND-OFF (2, 4, 13)
A. PRE-INSTALLATION FACTORS <ul style="list-style-type: none"> • MODULE FACTORY COST • EASE OF STORAGE, SHIPPING AND HANDLING • PRODUCT MATURITY • SHIPPING WEIGHT PER UNIT AREA • SHIPPING VOLUME PER UNIT AREA • SHIPPING AND HANDLING DURABILITY 	 16	 15	 15	 18
B. COMPATIBILITY WITH RESIDENTIAL CONSTRUCTION <ul style="list-style-type: none"> • COMPATIBLE WITH STANDARD CONSTRUCTION PRACTICE • STANDARD TOOLS AND EQUIPMENT • MINIMUM RISK TO NORMAL BUILDING FUNCTION • STRUCTURAL COMPATIBILITY WITH BUILDING • CONSTRUCTION TRADE COMPATIBILITY 	 16	 6	 16	 13
C. INSTALLATION <ul style="list-style-type: none"> • NEED FOR ADDITIONAL OR SPECIAL WEATHERPROOFING • MINIMUM ADDED STRUCTURE • ELECTRICAL CONNECTIONS PER UNIT AREA • MECHANICAL ATTACHMENTS PER UNIT AREA • EASE OF HANDLING BY ONE OR TWO PERSONS • INSTALLATION HANDLING AND DURABILITY • FIELD CABLING REQUIRED • EASE OF GROUNDING 	 19	 11	 19	 17
D. MAINTENANCE AND WARRANTY <ul style="list-style-type: none"> • MAINTENANCE FREQUENCY • EASE OF MODULE REPLACEMENT • OVERLAP OF WARRANTY RESPONSIBILITY • INTERFERENCE WITH NORMAL BUILDING MAINTENANCE • SUSCEPTIBLE TO VANDALISM • SAFETY • PRODUCT LIFE 	 15	 12	 15	 17
E. OPERATION <ul style="list-style-type: none"> • ARRAY EFFICIENCY AT NOC • OPLRATING DC VOLTAGE COMPATIBLE WITH EXISTING INVERTER REQUIREMENTS • RELIABILITY • WEATHERABILITY • SAFETY 	 6	 9	 6	 17
F. POTENTIAL FOR CODE COMPLIANCE <ul style="list-style-type: none"> • POTENTIAL TO MEET UL 790 CLASS B (FIRE) • POTENTIAL TO MEET NATIONAL ELECTRIC CODE REQUIREMENTS • COMPATIBILITY WITH EXISTING BUILDING CODES 	 7	 7	 7	 7
G. ACCEPTANCE <ul style="list-style-type: none"> • AESTHETICS • INSURABILITY • APPLICATION FLEXIBILITY • BUILDER/ARCHITECT ACCEPTANCE • HOMEOWNER/COMMUNITY ACCEPTANCE 	 16	 10	 16	 11
TOTAL SCORE	95	70	94	100

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Table 3-3. Concept Evaluation Matrix

O-SOLAR COMMERCIAL TEGAL (7)	ARCO SOLAR BLK IV + DIRECT (16)	ARCO SOLAR COMMERCIAL STAND OFF (2,4,13)	SOLAREX BLK IV STAND OFF (5,17)	SOLAREX BLK IV + STAND-OFF (8)	GE BLK IV DIRECT (6,15)	GE RECT SHING DIRECT (18)	GE NEW INTEGRAL (19)	ASEC BLK IV+ INTEGRAL (10)	ASEC NEW INTEGRAL (9)	MOTOROLA BLK IV RACK (14)	MOTOROLA BLK IV + STAND OFF (12)
 15	 15	 18	 12	 12	 17	 18	 13	 11	 11	 14	 15
 6	 16	 13	 13	 13	 16	 16	 6	 6	 6	 10	 13
 11	 19	 17	 17	 17	 24	 27	 23	 20	 20	 10	 15
 12	 15	 17	 17	 17	 24	 23	 14	 14	 14	 20	 15
 9	 6	 17	 14	 14	 17	 17	 12	 11	 12	 18	 17
 7	 7	 7	 7	 7	 10	 10	 6	 7	 7	 8	 7
 10	 16	 11	 12	 12	 18	 18	 11	 10	 10	 5	 10
70	94	100	92	92	126	129	86	79	80	85	92

2 FOLDOUT FRAME

2. Rack-mounted residential arrays rank low. The use of rack-mounted arrays on residential installations is not seen to have a wide range of applicability.
3. Stand-off mounted approaches also ranked relatively high. Many features of the stand-off mounted approach are attractive for a residential application. This is particularly true when applicability to the retrofit market is considered.
4. Integral mounting schemes must solve potential problems. The basic integral mounting concept has many desirable features in a residential application, but the existing systems which use this approach have potential shortcomings which must be addressed if this scheme is to be extensively employed in residential photovoltaic installations. The use of gasketed joints for weather tightness and the non-standard spacing and tight positioning control required for the rafters are examples of potential problem areas which must be addressed if this mounting approach is to prove a viable option.

3.4 LESSONS LEARNED FROM EXISTING APPROACHES

The evaluation of the existing or proposed residential array installations has served to highlight several areas of concern with respect to the criteria which could have a potentially fatal impact on the acceptance or long-term performance of these arrays in a residential application. In particular, the following concerns are worthy of further consideration in the formulation of the three module/array design approaches to be evaluated as part of the Task 1 activity:

1. Metal substrates lead to reliability and safety problems. Many instances of short-to-substrate failures with associated arcing have been experienced in modules with metal substrates.
2. Exposed conductive elements require grounding with associated cost. All exposed conductive elements of the modules and array must be electrical bonded and grounded for personnel safety unless a dual insulation system is employed within the module between the active circuit components and the exposed conductive parts. The field installed wiring associated with this grounding network can constitute a significant fraction of the total installation cost of the array.

3. Polymeric outer covers have questionable long-term weatherability and spread-of-frame resistance. There is a considerable uncertainty regarding the ability of polymeric outer covers to adequately protect the encapsulated cell assembly and transmit the incident illumination without significant degradation over the 20 year design lifetime of residential modules. In addition, it is doubtful that a plastic film-covered module could successfully pass either the spread-of-frame or intermittent-flame tests specified in UL790, "Tests for Fire Resistance of Roof-Covering Materials."
4. Access to the space between the underside of a stand-off mounted array and the roofing surface must be blocked. The perimeter of a stand-off mounted array must be suitably screened to prevent the accumulation of leaves in the air space under the modules. This space would also provide an excellent nesting spot for birds, squirrels, and hornets.
5. Safety is a critical design concern. Personnel and fire safety are perhaps the most important concerns facing the module/array designer and system installer. The recently published preliminary module construction requirements (JPL Document 5101-164) defines many of the design features required to produce the necessary level of product safety for the module. However, to-date little attention has been given to the over-all safety aspects of the installed solar array. Electrical safety during both the installation and operational periods is important since the generated voltage levels at the dc bus will typically exceed 200 volts above ground potential. The use of aluminum ladders during module installation, as was observed on at least one NE RES prototype, is not a wise practice. It was also noted that several of the existing array installations are configured to have high voltage levels near the gutter line at the eave. With this array electrical circuit arrangement there is the likelihood that the homeowner could accidentally come in contact with high voltage circuit elements during the process of cleaning the gutters of leaves or ice dams.

3.5 SELECTION OF THREE MODULE/ARRAY CONCEPTS

3.5.1 DESIRABLE MODULE DESIGN FEATURES

In the synthesis of the three module/array concepts to be investigated in the latter part of the Task 1 activity it is important to first define design features which would be desirable in the light of the experience with existing systems. As mentioned earlier, the incorporation of a dual insulation system within the module would obviate the need to ground exposed conductive elements of the module or array with associated cost savings in the array installation. The elimination of exposed conductive parts constitutes another positive electrical safety measure which enhances the overall product safety. Likewise, if the power system ground potential were maintained along the gutter line at the eave, the system design would present a minimum electrical shock hazard to the homeowner.

It is also apparent that the use of high efficiency square or rectangular solar cells with associated high module packing factor is essential to minimize the overall installed cost of the solar array since, as the cost of solar cells is reduced, the installation costs and the materials cost of the other module and array components, which are proportional to the array area, will become the major factors determining the overall array installed cost. In the development of the three candidate design concepts it is proposed to use the solar cell described in Figure 3-10 as the basic building block. This nominal 100 mm square cell is postulated to have an average base cell efficiency of 13 percent which is a reasonable goal for either semi-crystalline or HEM wafer technology. A multiple top contact solder pad configuration has been depicted as one approach to providing the cell contacting redundancy required by the use of two interconnector strips soldered across the entire width of the cell.

3.5.2 MODULE SIZE CONSIDERATIONS

The selection of an appropriate module size is one of the first issues to be addressed in the formulation of candidate residential module designs. This is a complex question since its resolution must consider such factors as: (1) residential roof size constraints, (2) individual module open-circuit voltage limitations for electrical safety, (3) input voltage constraints for inverters which operate into a residential 240 volt single phase ac line, (4) the physical placement of power system ground potential along the gutter line, (5) the structural constraints

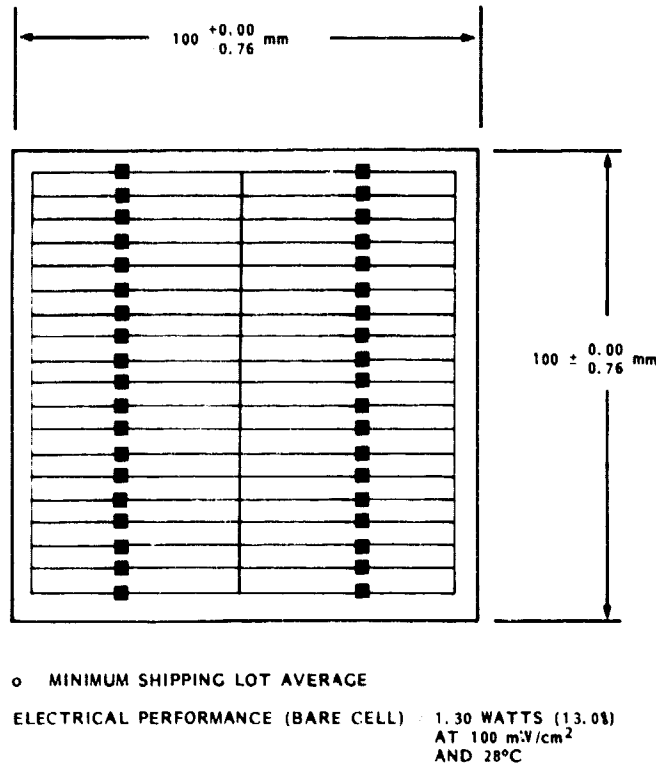


Figure 3-10. Typical Solar Cell Geometry and Electrical Performance

imposed on the installed modules by wind, snow and dead weight loads, (6) the structural implications associated with handling and shipping loads, (7) the building structural modifications required to accommodate the loading due to the photovoltaic array, and (8) the ability of one or two persons to handle and install the modules without the use of mechanical lifting or positioning devices. When those various factors and constraints are considered in combination it becomes clear that there is a practical upper limit to the size of the unit which is pre-assembled to be carried up to the roofing surface for ultimate installation as part of the photovoltaic array. The modules or panels should be as large as this practical upper limit to minimize the number of discrete components which must be attached to the roof structure and electrically interconnected to form the array.

The photovoltaic roof shapes and sizes for the five preferred designs from the Sandia flat-panel residential systems study are given in Figure 3-11. Of particular interest in this investigation is the slant height of the roof surface, or the eave-to-ridge distance, which varies

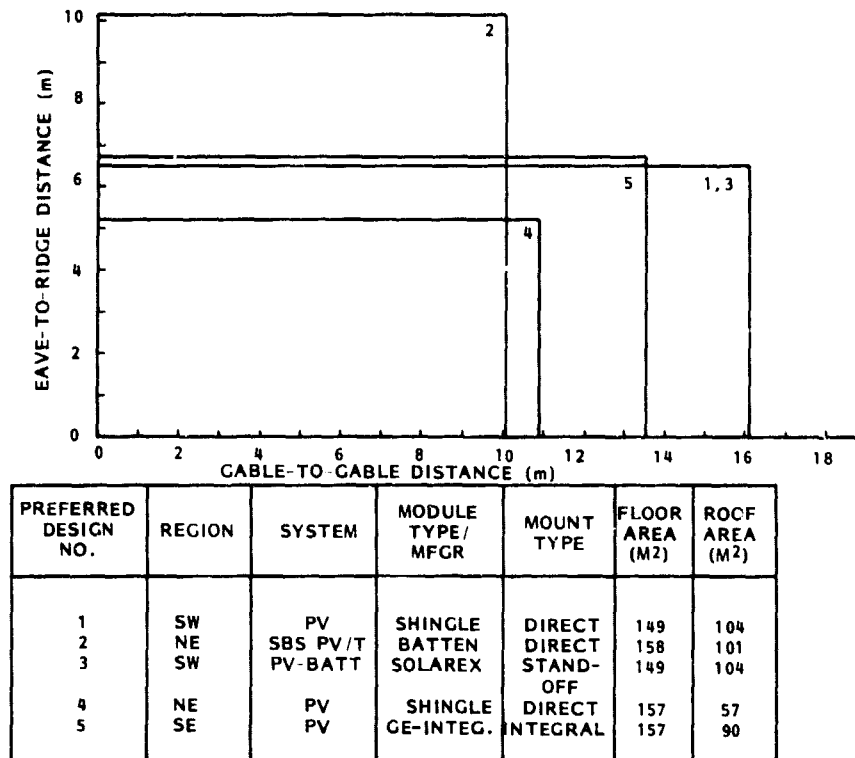


Figure 3-11. Photovoltaic Roof Sizes and Shapes for Typical Residential Installations

from about 5.2 to 10.2 m in these designs. If the upper limit of this range is considered as the practical maximum value, Figure 3-12 illustrates how this constraint can be combined with the module open-circuit voltage electrical safety criteria and the inverter input voltage requirement to produce an upper limit on the module dimension in the slant height direction. Thus, the 30 Vdc limit on module open-circuit voltage for electrical safety limits the number of series-connected cells to 44 as shown in the figure. When this limitation is coupled with the requirement to generate an array maximum power voltage of 200 Vdc at NOC, the minimum required number of series-connected modules can be calculated as shown in the upper right-hand quadrant of the figure. This can be translated into a roof slant height requirement for various module dimensions as shown in the lower right-hand quadrant. This analysis shows that a module dimension of 0.61 m (2 ft) is the maximum that can be accommodated within the assumed constraints which explicitly place the power system ground potential along the gutter.

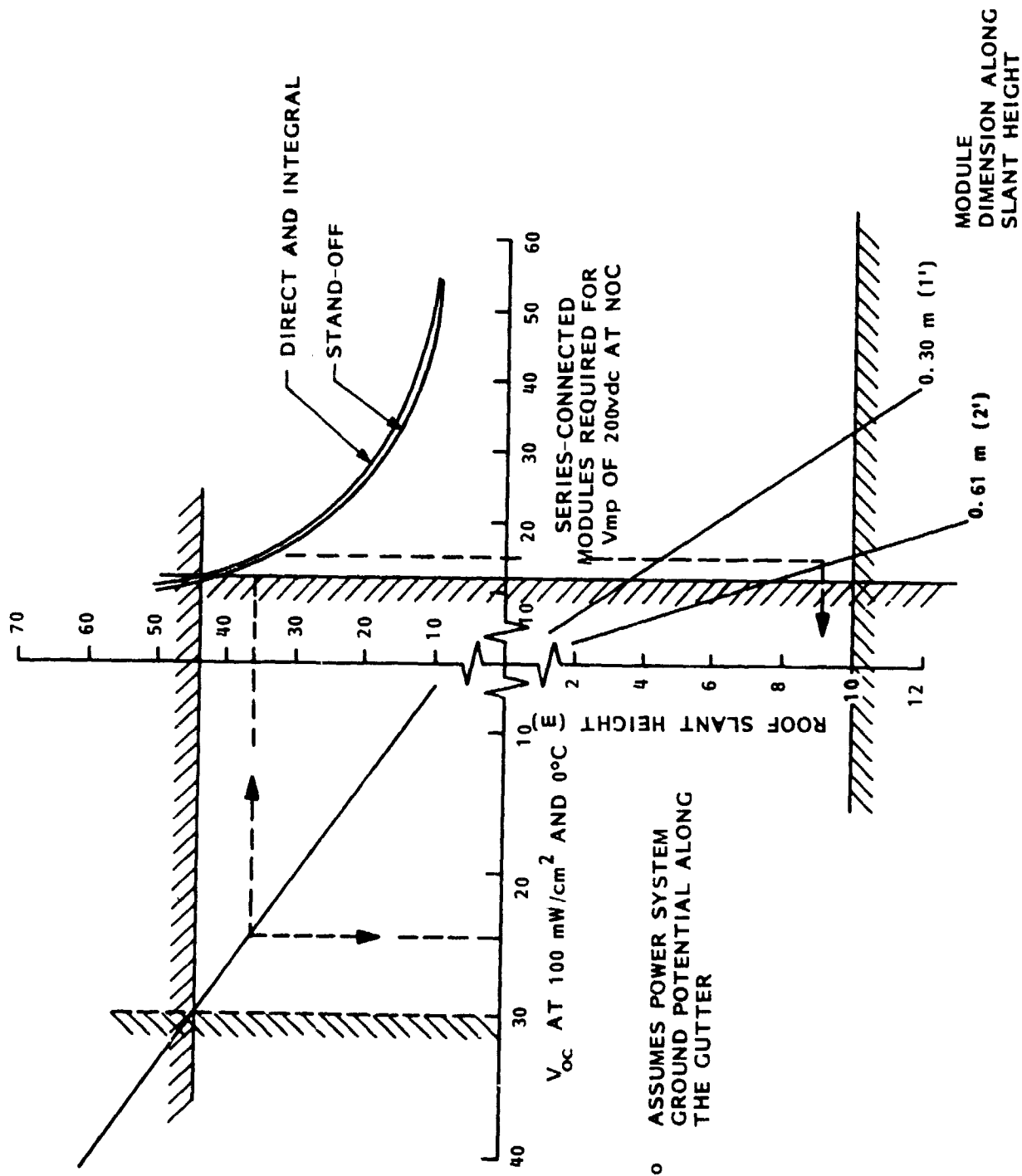


Figure 3-12. Residential Array Electrical and Mechanical Constraints Which Limit Module Size

The size of a simply supported glass superstrate module was investigated from the standpoint of installed structural loading using the nonlinear techniques reported by Moore in JPL Document No. 5101-148. The results summarized in Table 3-4 were obtained for a combined load consisting of the module dead weight, a 70 mph wind and a 52 lb/ft² snow load. This analysis shows that a 2 by 4 foot annealed glass plate size is the upper limit allowable by a worst case combination of operational loads. A plate thickness of 0.188 inches (5 mm) was selected for this analysis since it represents the maximum stock thickness available for high transmission, low-iron, soda-lime glass. The areal density of this glass plate thickness will yield a total array installed weight which is compatible with typical residential construction. The use of a significantly thicker glass superstrate, which constitutes the major fraction of the array installed weight, will probably require a structural analysis with possible modifications to what would normally be specified for the residence without a photovoltaic installation.

Table 3-4. Results of Structural Analysis for Various Glass Plate Sizes

Glass Size (ft x ft)	Glass Thickness (inches)	<u>Predicted Stress</u> <u>Breakage Stress</u>	Conclusions
4 x 8	0.188	> 1	Unacceptable
4 x 4	0.188	~ 1	Marginal
2 x 4	0.188	< 1	Acceptable
2 x 2	0.188	< 1	Acceptable
1 x 2	0.188	< 1	Acceptable
1 x 1	0.188	< 1	Acceptable

The installation cost of the photovoltaic array will also increase with the areal weight of the modules or panels which must be handled and lifted from ground to roof level. Figure 3-13 presents some of the handling and lifting considerations associated with modules of various sizes. The basic 2 by 4 foot module represents the upper limit of a unit size which can be practically lifted and handled by one man.

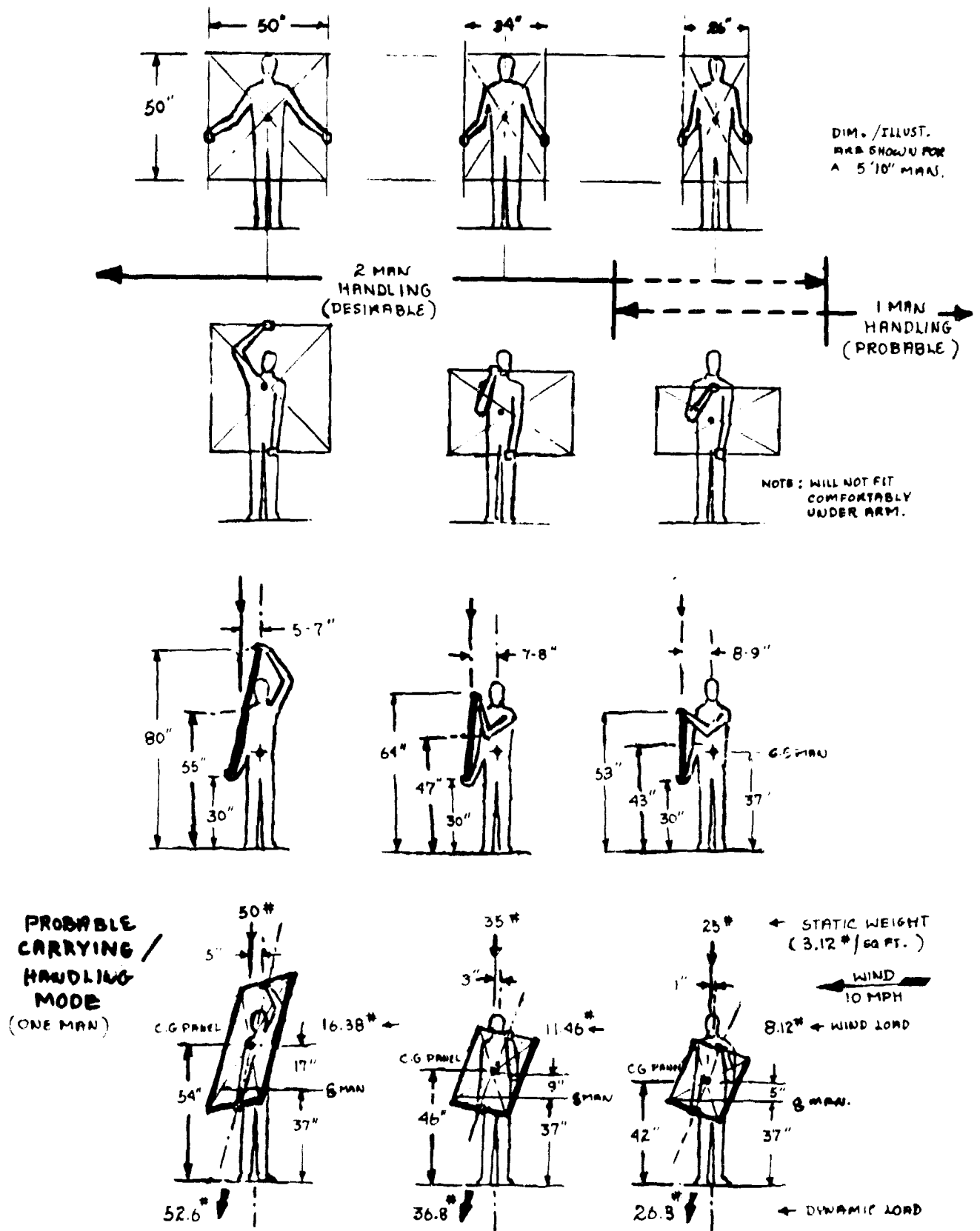


Figure 3-13. Residential Module Handling Considerations

These considerations, when coupled with the roof size constraints and module and array electrical requirements, lead to the conclusion that a basic 2 by 4 foot module size is near optimum for the majority of residential installations.

3.5.3 MODULE ELECTRICAL CIRCUIT CONFIGURATION

A module electrical circuit configuration which uses 100 mm square cells in a basic 2 by 4 foot module format was specified for use with each of the three conceptual designs. Figure 3-14 gives the electrical circuit schematic for a 72 cell module consisting of the series-connection of 36 cell pairs. A by-pass diode is connected across each group of 12 series-connected cell pairs. This electrical circuit is arranged on the glass coverplate as shown in Figure 3-15, which is a view looking at the rear of cell circuit. The basic building block of this circuit is a unit consisting of six series-connected cells. Two such units are cross-strapped at each cell pair to form the six series by two parallel circuit element which is repeated, with alternating polarity, six times across the width of the module. The alternating current flow direction of these circuit elements makes it possible to conveniently install the by-pass diode chips at the locations shown.

This circuit configuration, which is expected to produce the output characteristics shown in Figure 3-16, has been evaluated with respect to hot-spot heating due to cell shadowing and cracking and found to yield acceptably low temperatures at the dissipation sites.

3.5.4 PRELIMINARY DESIGN DESCRIPTION FOR EACH CONCEPT

3.5.4.1 Encapsulated Cell Assembly

An encapsulated cell assembly has been selected as a common element among the three designs. Except for small differences in the size of the glass coverplate and in the placement of the by-pass diode, this same basic module encapsulation system will be employed for each design. As shown in Figure 3-17, this encapsulation system consists of a 0.188 inch (5 mm) thick glass superstrate with EVA/Craneglass film used on both sides of the cell circuit as the encapsulant. A laminate of Tedlar and aluminum foil covers the rear surface and functions as both an insulation system and a moisture barrier.

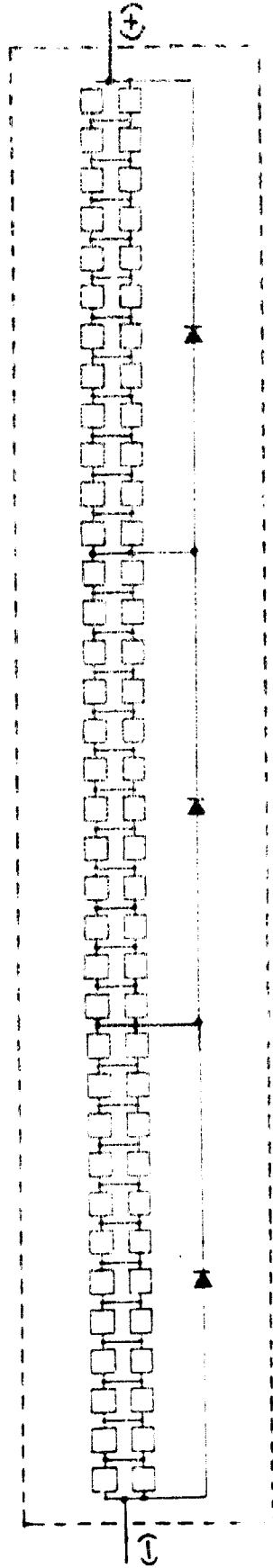


Figure 3-14. Module Electrical Circuit Schematic

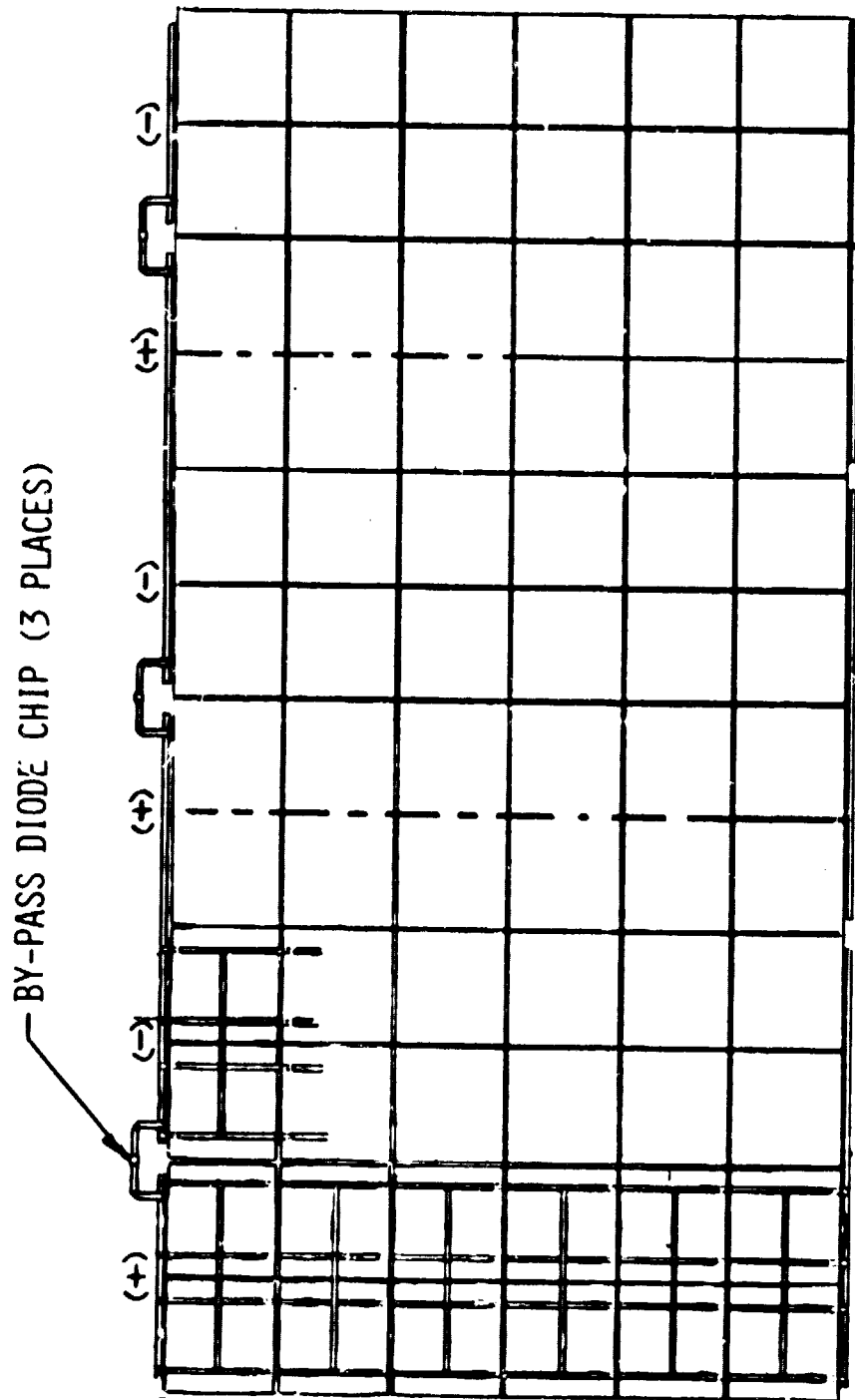


Figure 3-15. Circuit Mechanical Arrangement

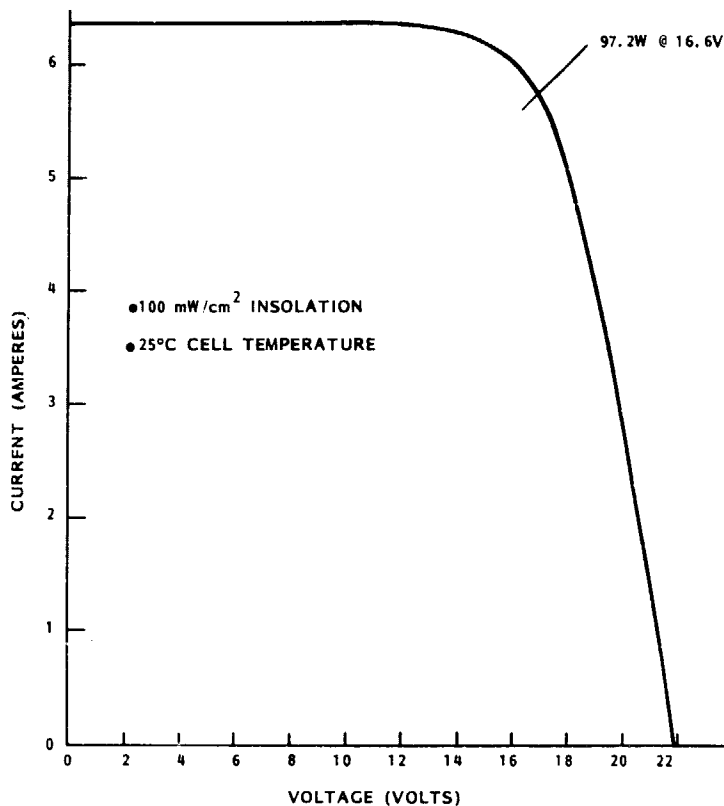


Figure 3-16. Expected Module I-V Characteristic Under Peak Power Rating Conditions

3.5.4.2 Concept No. 1 - Direct-Mounted, Overlapping Shingle

A direct-mounted, overlapping shingle module, which is configured as shown in Figure 3-18, is identified as Concept No. 1. This module approach is an evolution of the hexagon shaped shingle module which was developed under the JPL Block IV program. The overlapped substrate portion of the module consists of a bonded lamination of a Flexseal outer skin, a closed cell foam core and a Pan-L Board rear cover.

The staggered overlapped pattern of this array installation requires the use of half-width modules on alternating courses at the gables of the roof. The electrical circuit configuration described in Section 3.5.3 can be easily adapted to this half-width by simply eliminating the parallel connections which form cell pairs. In this way, it is possible to produce a half-width module which generates the same voltage as a full-size module at half the output current.

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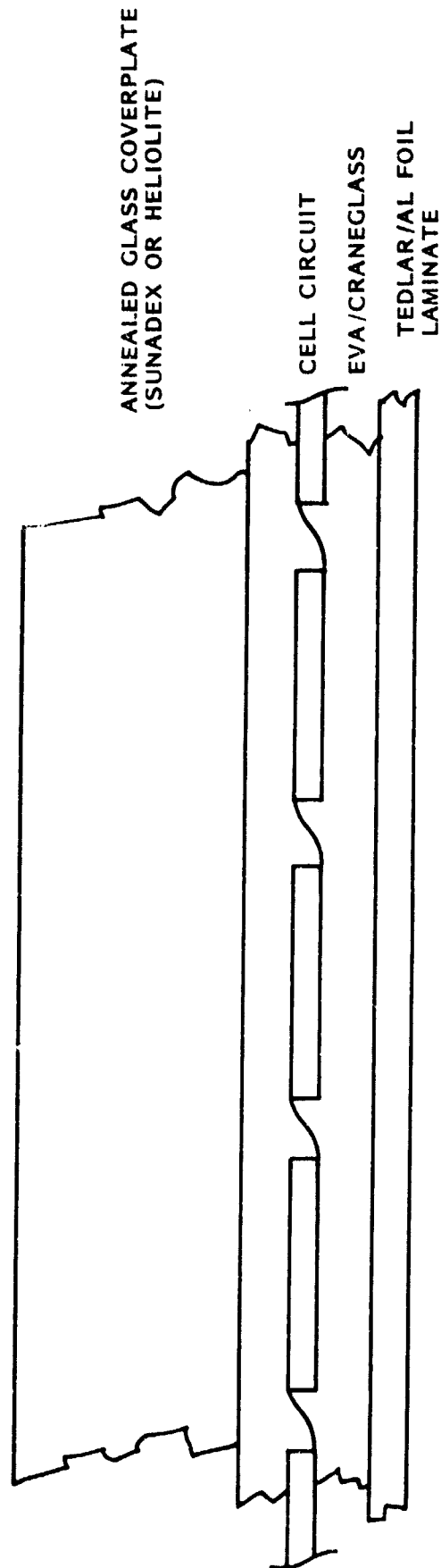


Figure 3-1'. Module Encapsulation System

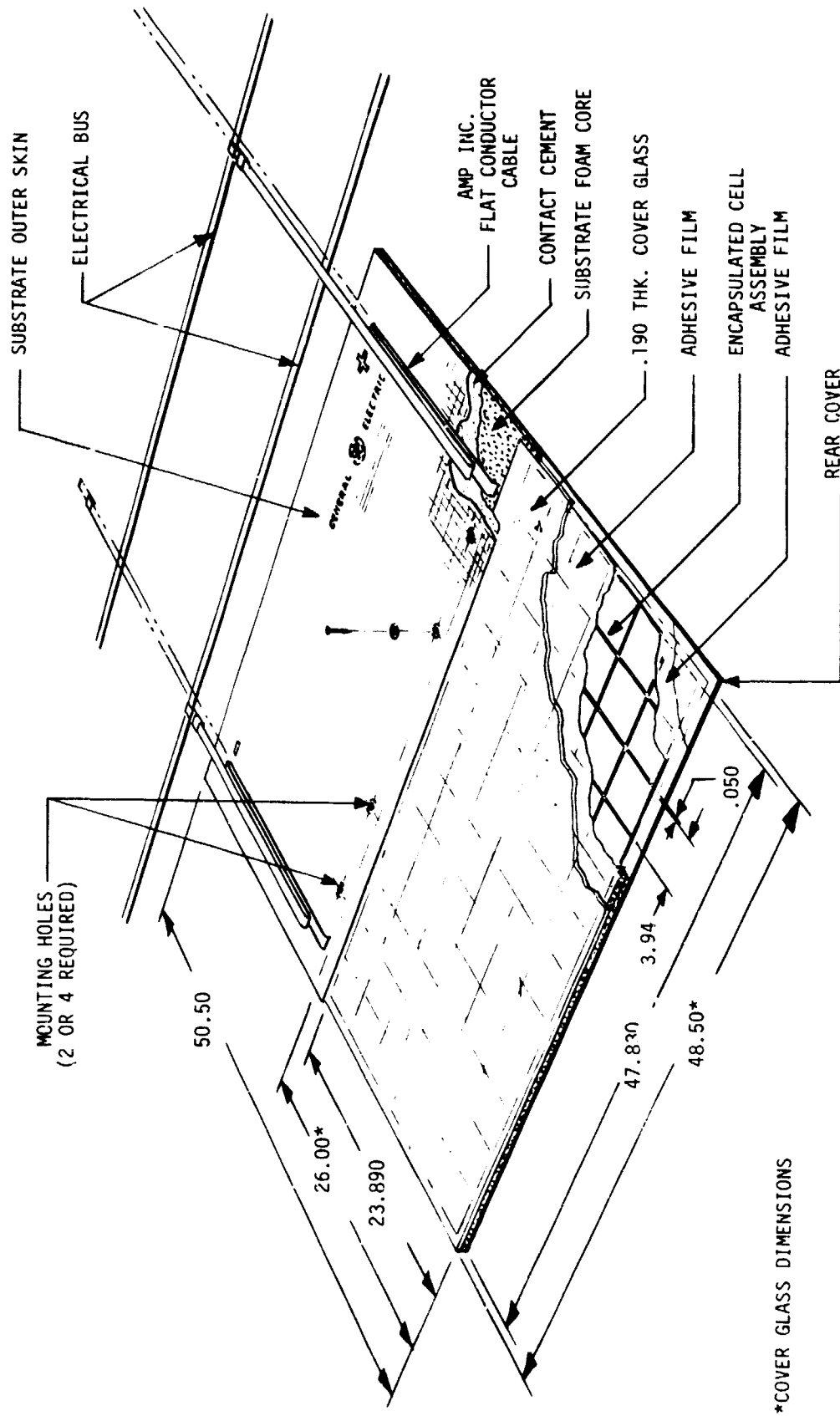


Figure 3-18. Concept No. 1 - Direct-Mounted, Overlapping Shingle

3.5.4.3 Concept No. 2 - Integrally Mounted Module With Plastic Tray

An integrally mounted module, which employs an underlying plastic tray as the interface with the roof support structure, has been proposed as Concept No. 2. Figure 3-19 shows the overall dimensional details of this configuration while Figures 3-20 and 3-21 are sketches of sectional views taken through the east/west width of the module and through a lap joint along the slope of the roof, respectively. The use of a plastic tray in this configuration introduces a dual insulation system between the active elements of the solar cell circuit and any metallic element which may be used to mount the modules to the roof structure. This electrical safety design approach thus eliminates the need to ground these metallic elements of the array installation.

3.5.4.4 Concept No. 3 - Stand-off Mounted Module With Aluminum Frame

Concept No. 3 represents a more conventional design approach which employs an aluminum extrusion frame around the module perimeter to function as the interface with the roof-mounted brackets of a stand-off installation. Figure 3-22 gives the overall dimensions of this module and illustrates the method of attachment to the roof mounted support members while Figure 3-23 shows some typical cross-sectional views of the construction.

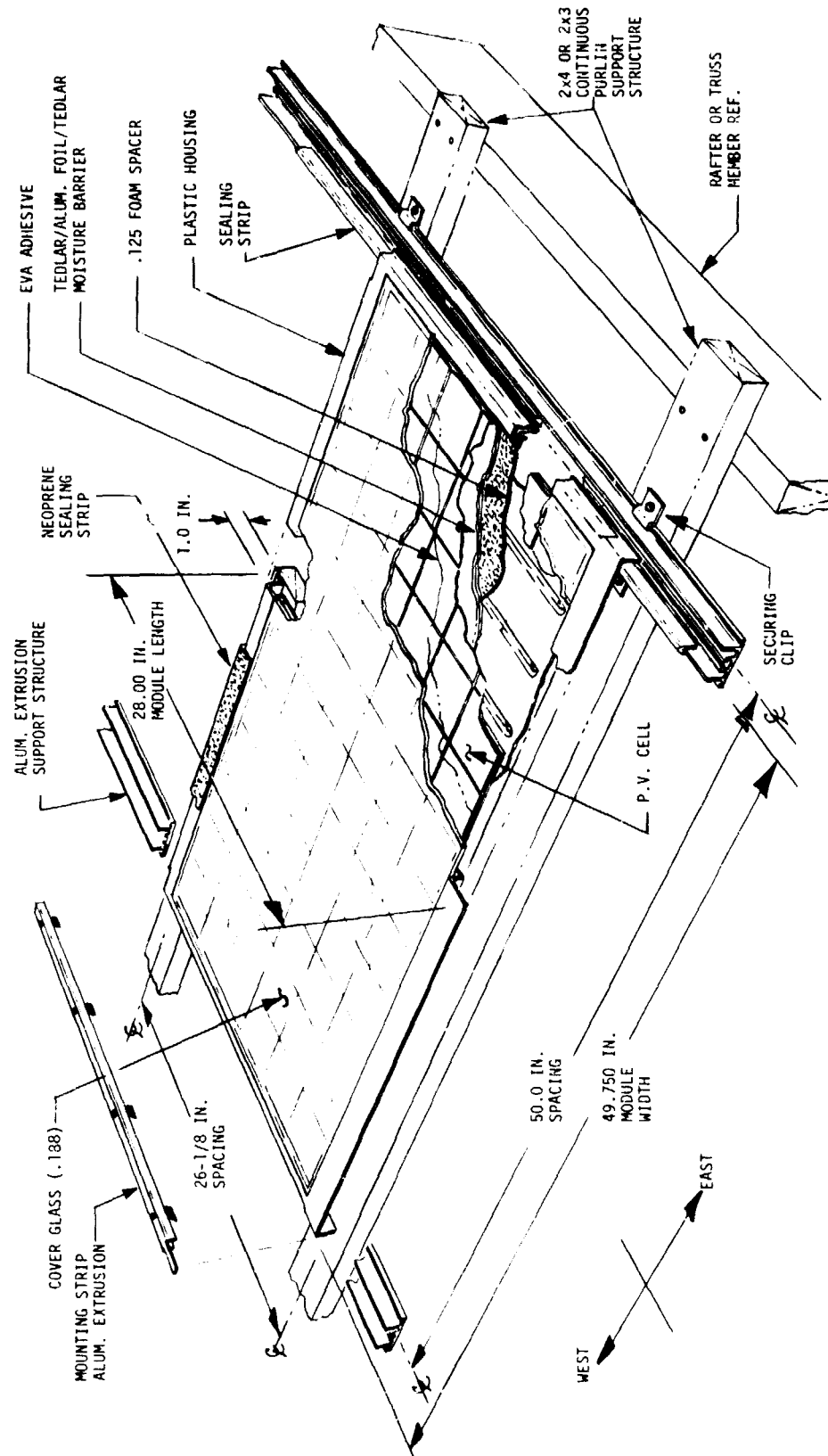


Figure 3-19. Concept No. 2 - Integrally Mounted Module with Plastic Tray

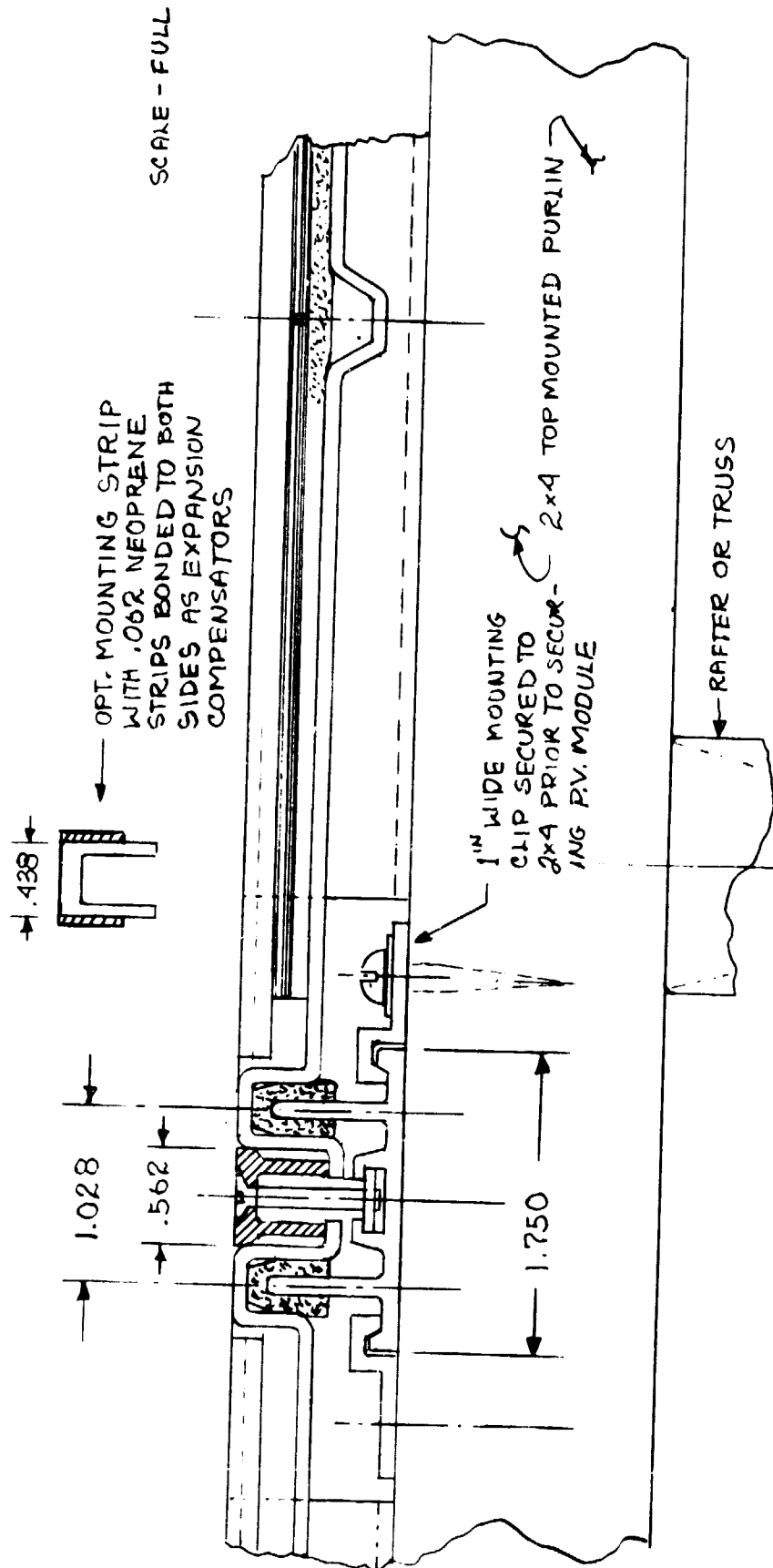
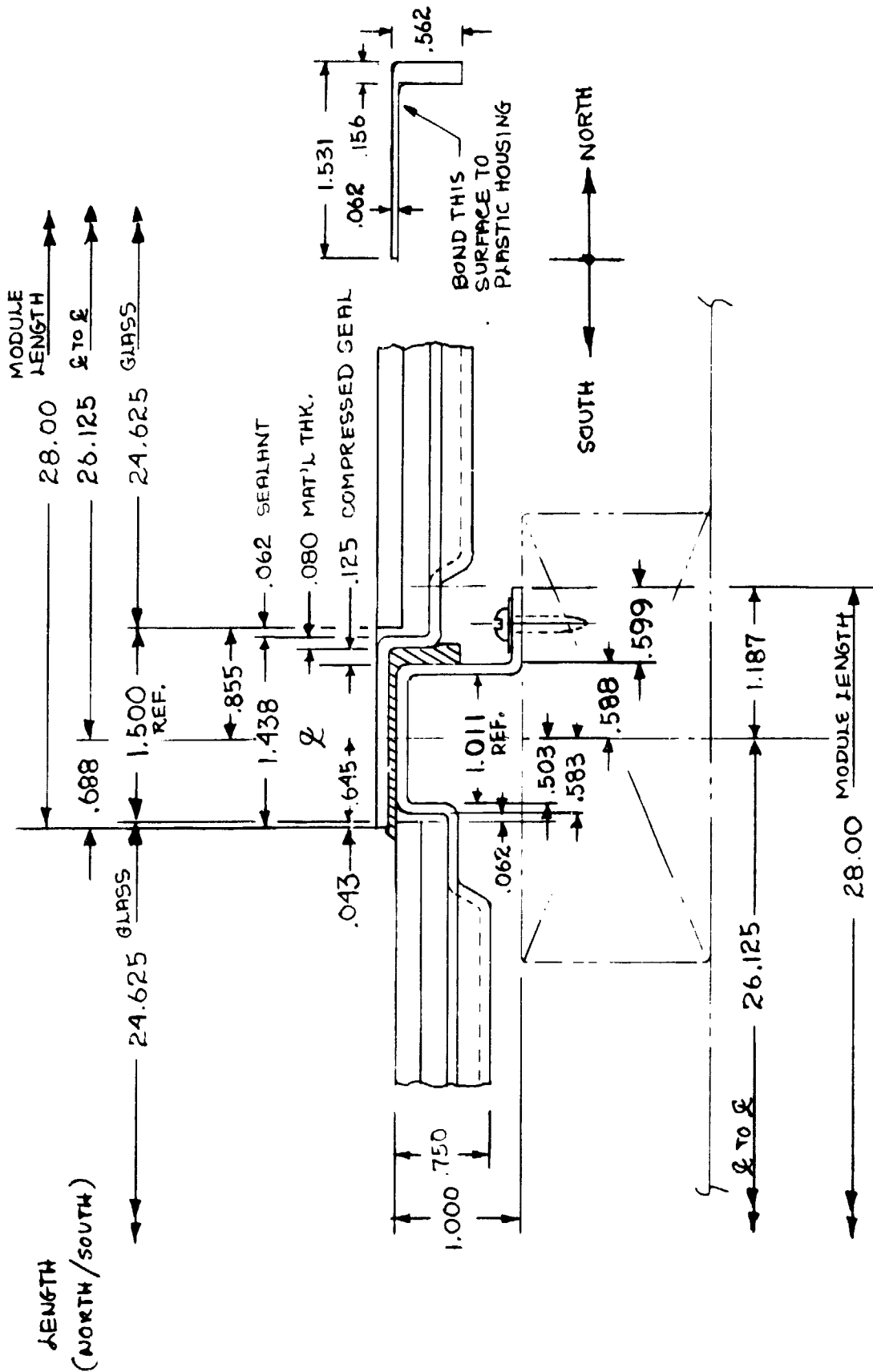


Figure 3-20. Sketch of Module Cross-section in the East/West Width Direction

INTEGRAL MOUNT PHOTOVOLTAIC MODULE
(HORIZONTAL PLASTIC HOUSING CONFIGURATION)

* VACUUM FORMED HOUSING



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Figure 3-21. Sketch of the Module Overlap Along the Roof Slant Height

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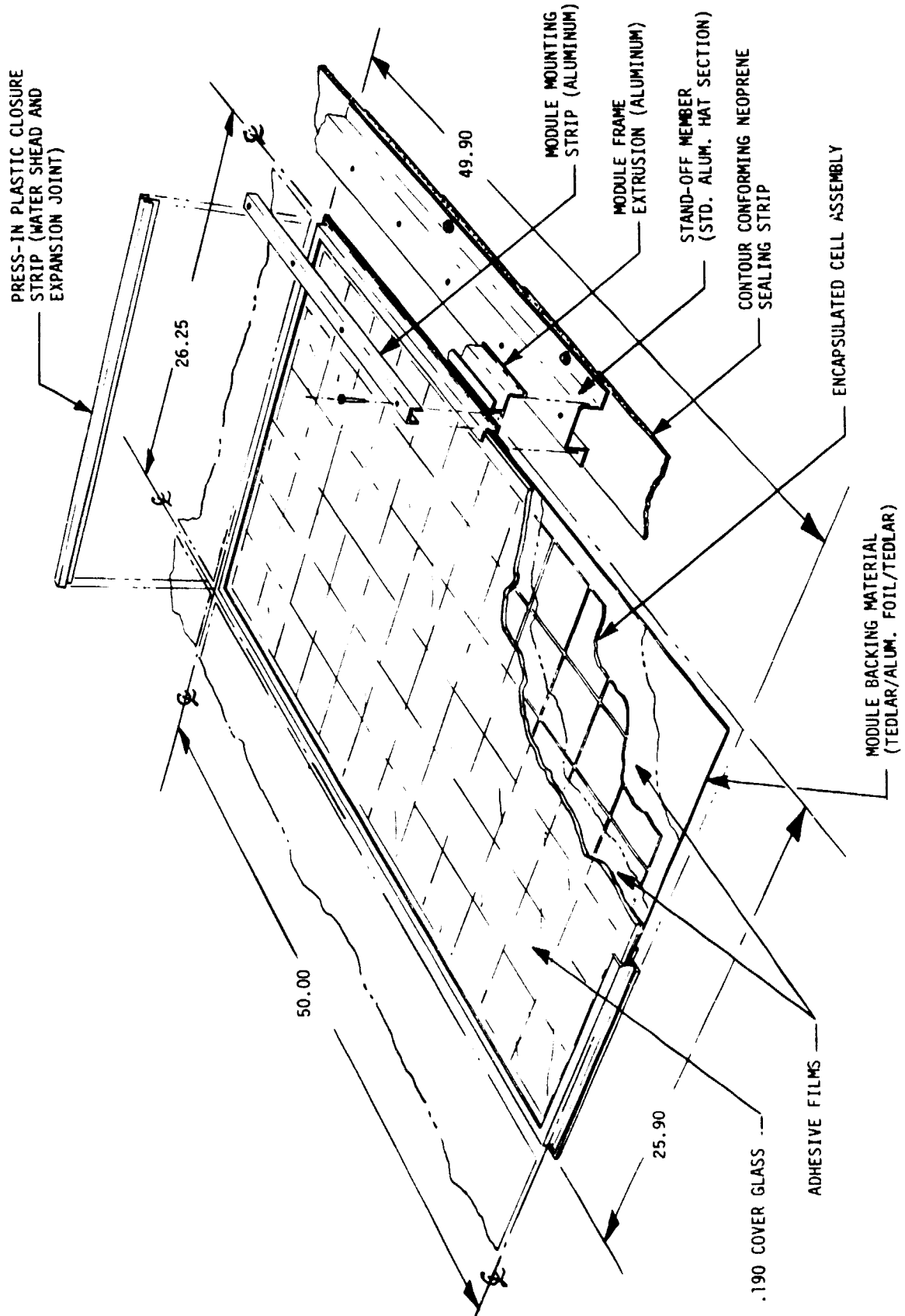


Figure 3-22. Concept No. 3 - Stand-off Mounted Module with Aluminum Frame

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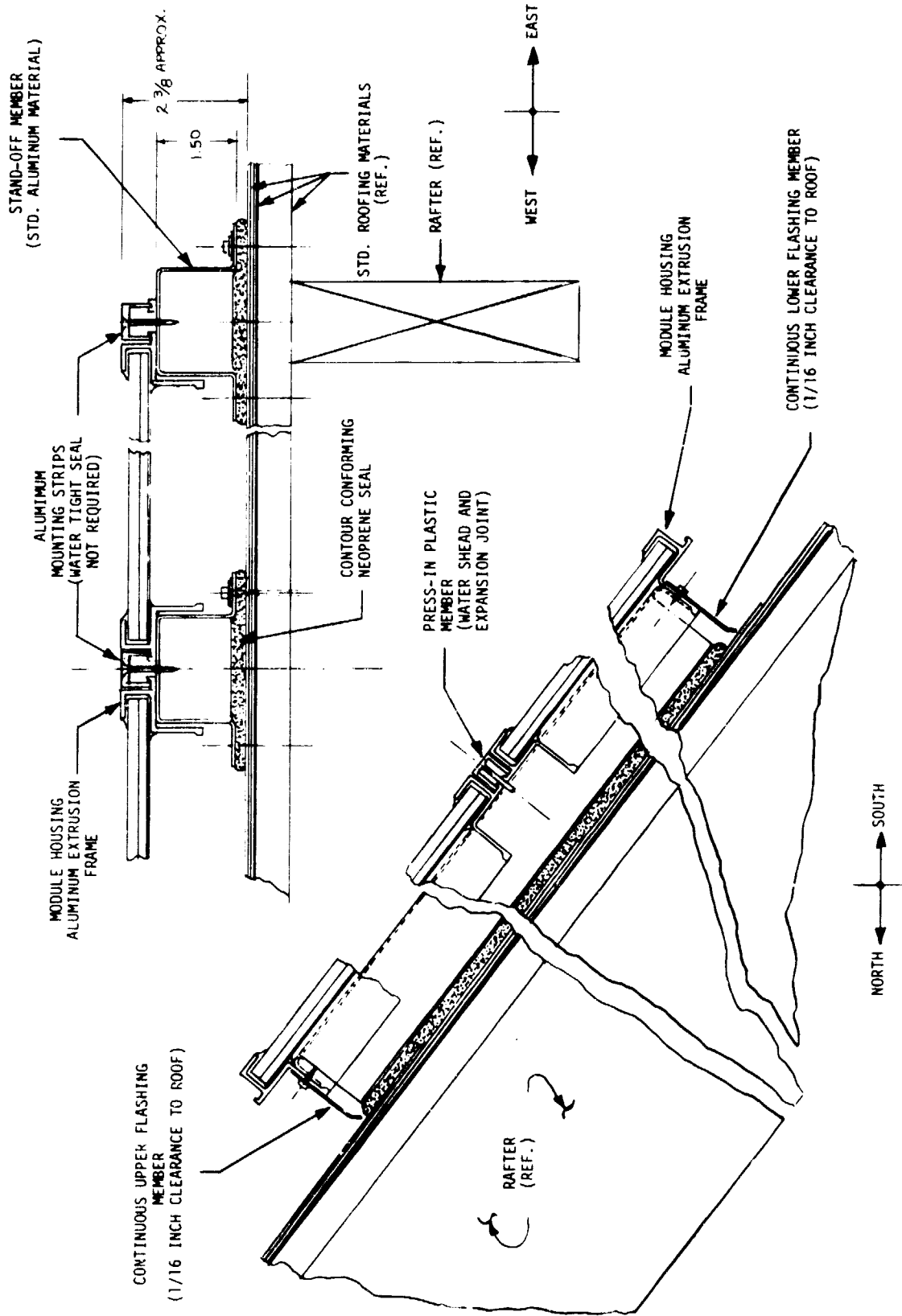


Figure 3-23. Cross-sectional Views of the Stand-off Mounted Array Installation

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

SECTION 4

CONCLUSIONS AND RECOMMENDATIONS

The evaluation of existing or proposed residential array concepts has led to the selection of three different baseline module design approaches to be studied in further detail as part of an optimization process which will ultimately lead to the selection of one concept.

These three candidate module design concepts, which include a rectangular overlapping shingle, an integrally mounted module with a plastic tray substrate and a stand-off mounted module with an aluminum frame, have been selected based on a comprehensive review of the existing residential array designs. In each case an effort has been made to incorporate design features which were thought to improve upon the shortcomings of the existing designs as noted during the evaluation process.

It would seem desirable from the standpoint of the electrical safety of the installed array to impose the requirement that power system ground potential be maintained along the gutter line of the south-facing roof. This condition is not present on many of the existing residential photovoltaic installations. The rationale for considering this as a desirable safety precaution rests with the concern that the homeowner may often be required to clean accumulated leaves, debris, ice and snow from the gutter and that an aluminum ladder and a sharp metallic tool may be employed in this task. The imposition of this constraint on the array design, when coupled with module open-circuit voltage limitations and inverter input voltage requirements, leads to the selection of 2 feet as the maximum module dimension along the roof slant height if realistic roof aspect ratios are to be maintained. The further consideration of the structural loads for annealed glass superstrates suggests that a basic 2 by 4 foot is the practical maximum module size for residential applications. The handling and lifting aspects of this application also support this selection.